Advanced Robot Systems

by

Mark J. Robillard

高级机器人系统

(英3-7/1577)

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Howard W. Sams & Co., Inc.
4300 WEST 62ND ST. INDIANAPOLIS, INDIANA 46268 USA

Mark J. Robillard has been actively involved in microcomputing for over ten years. He is currently involved in the research and development of advanced color graphics systems and voice recognition peripheral design. He writes for *Robotics Age* magazine and *Microcomputing* magazine and has written *Hero I: Advanced Programming and Interfacing* and *Microprocessor Based Robotics*, both published by Howard W. Sams & Co., Inc.

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Preface

In many technological fields, advances are made every day. Corporate product development programs advance the state of the art by their very nature. Everybody is striving to build yet a better mousetrap. The engineers, technicians, and scientists involved in these endeavors advance their state of learning. It would seem that to advance is the intended natural way.

This book too, being titled *Advanced Robot Systems,* promises to show a chronicle of advancement. In fact, it does this, however, not as advancement in the field of robotics, but rather, as a more advanced volume of information when compared to its previous volume *Microprocessor Based Robotics*. It is true, though, that the information contained here has certain advanced characteristics.

This is the first technical book that stresses the systems approach to the design of robots. Throughout these six chapters, you will find in-depth examples of robot systems hardware and software. At this time, let me summarize each of the chapters to give you a better feel for how all this fits together.

To start off, Chapter 1 leads into a discussion of the design of wheeled "rover" robots. Presently, this type of locomotion is the most popular, given the technological problems involved with other types of motion, e.g., walking. Throughout the hardware discussions, you will be presented a philosophy with which to design by. This constitutes the basis for all systems discussions throughout the book.

Three rover applications are presented. The *automated guideway vehicle (AGV),* used on today's factory floors, the mailroom robot that traverses our office building's hallways delivering interoffice memos and mail, and tomorrow's security robots are each studied in depth. Their hardware requirements and several approaches to satisfying these form the bulk of the information presented in this chapter.

Chapter 2 complements the work presented in the first chapter by showing the software involved in rover systems. Starting off, there is a general discussion of the age-old problem dealing with where the software-hardware split should occur and where it is most cost effective. Several programming examples written in standard BASIC language are given. In instances where machine language would be more appropriate, detailed flowcharts are given on every operation.

Chapter 3 breaks away from the rover mold to deal with the aspects of designing hardware-based control systems for manipulators. In particular, several LSI stepper-motor controller ICs are discussed. The design of an XY table manipulator is presented with applications in the pick-and-place assembly field.

Chapter 4 is probably the most complex; in-depth presentation is given of simulation programs for robot manipulators. Two complete BASIC programs are designed and discussed in their entirety. The first deals with the control of the stepper-motor ICs discussed in Chapter 3. This program allows a personal computer, suitably equipped with a parallel interface (details given), to control the actions of the XY table presented earlier. This control is through the use of English language commands entered through a keyboard or obtained from another computer through an RS232 link.

The second program presented is a full graphics simulation of both the XY table and the control structure presented earlier. This program is for those of you who do not wish to invest the time and effort in actually building robot hardware.

Chapter 5 deals with the popular subject of personal robots. In particular, it deals with the hardware approaches used in both the Heath, HERO 1, and the RB Robot, RB5X. Emphasis, in this chapter, is put on distributed approaches to hardware design.

A completely new personal robot system is discussed and designed in these pages. Here, you will find schematics of ultrasonic rangers, motion detectors, and full robot CPUs.

The last chapter (Chapter 6) ties together all the above under the guise of personal robot software. Actually, many of the concepts presented in all the chapters are reviewed and interwoven to produce a new programming language: ROBOL. Also discussed is the distribution of robot software, adding artificial intelligence and auto adaptive learning techniques.

This volume does not intend to present all that is known about robot systems. Nor does it present all that there is to know; however, it begins by defining the problems we face and shows some creative approaches to solving them.

MARK J. ROBILLARD

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I wish to thank the following for their support in the production of this volume and for providing necessary information on that wondrous HERO 1:

Jim Wilson — Heath Co.
Jim Lytle — Heath Co.
Doug Bonham — Heath Co.

and Joe Lombardo
for coming up with his own advanced ideas.

DEDICATION

I would like to dedicate this volume to the following people who have supported me throughout the years.

My mother, Rosemary
My father, Joe
Julia Healey (a supporter from day one)

My special dedication has to go, once again, to Angie, my wife. Thanks go to her for all her work and her many great ideas.

Contents

Chapter 1

Moving Platform Mechanics

When a machine is touted to be adaptable to its environment, it is generally meant that this same machine may be operated under varying conditions. In an automatic assembly environment, adaptability often pertains to a robot's ability to change tool heads or to maneuver to where the work is required. It is this latter ability that this chapter will attempt to shed light on.

In *Microprocessor Based Robotics,* we touched on the mechanics involved in a roving platform. Here the total system necessary to not only make it move but to do so in a precise, planned way is explored. We begin our journey with a discussion of what a roving robot is and how it is being used in industry today.

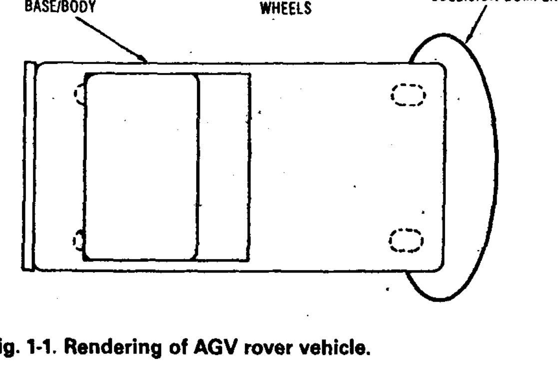


Fig. 1-1. Rendering of AGV rover vehicle.

MATERIAL-HANDLING SYSTEMS

Automated factories are seemingly springing up all over. Their claim to fame is that their output is a steady flow of finished goods 24 hours a day. Although many of today's factories are not making use of all 24 hours, significant savings in terms of raw materials and time have been realized.

Why a savings in materials? That's where we begin our story of the rover robot. It is these machines that are being utilized to carry raw materials to various workstations within a factory in a timely, efficient manner. Once there, they can be used to transport finished goods away from the site, therefore, effecting an ideal work flow. In this way they bring only the materials required at that particular moment in time. There is no need to stock a few spares of parts at the workstation in the instance that the material handler may be late. This cuts down on in-process inventory, which lightens the load on both materials and cost.

The workstations mentioned may be occupied with assembly workers or preprogrammed robot manipulators that mimic the job of the human assembler. The material transferred may be any type or shape. You will often find that in extreme cases where the particular material handled is of an odd or unwieldy shape that the rover platform will be fitted with a special tool or holder that positions the piece for easy mounting or unloading.

Fig. 1-1 shows us a rendering of a typical factory floor rover. The large bumper out front is a piece of spring steel fitted with several microswitches to detect a contact that might result in a collision. The bed of the robot is where the raw material or finished goods are placed. This particular drawing does not show any type of fixturing for special-shaped pieces. All control electronics are usually housed in the back command "tower." Many of these rovers are equipped with their own microprocessors that allow them to be programmed once and then they are free to travel on their route through the factory floor.

Not shown on the drawing is the mobility section of the machine. Obviously, some sort of wheeled arrangement is provided. However, if you remember the discussions from the previous volume in this series, there are many ways to effect motion. Most of the roving platforms used by industry have a conventional three- or four-wheel approach. Of course, there are multitudes of variations in the control methods used to make them roll, and those same microprocessors located in the control head perform that duty also.

Other methods of control are common also. There are some that receive radio commands from a master control station located in a fixed area of the factory. A command may be as simple as needing more material at workstation number 3, or it may be as complex as supplying a complete route map.

The rovers discussed thus far may be classified as *automated guideway vehicles (AGVs)*. They are called AGVs because most of the factories employing them have a complex route guideway "track" located somewhere on the surface of the floor. I hesitate to use the word "track" because more often than not there are no physical rails or even obvious paths that these machines seem to be confined to. They follow a buried wire in the floor where a low-frequency radio signal is transmitted. On-board guidance systems are able to detect the presence of this signal and to assure that they are centered over the guidepath. The wire is usually buried at least a quarter inch below the cement flooring to avoid becoming an obstacle. A local transmitter radios control information to the AGV as to which carrier frequency to follow (track) and can, therefore, effect a change of frequencies that may be used to switch the vehicle over to an adjoining guideway. Later in this chapter we will go over the operation of several types of invisible tracks and the control systems used to effect them.

Factories are not the only place roving robots are showing up today. They are, however, the most prevalent. As time goes on several other types of factory "helpers" will begin to surface.

SECURITY SYSTEMS AND MAILPERSONS

The subtitle "Security Systems and Mailpersons" may sound like a strange mix of disciplines. Actually, the two classes of activities outlined in it are two other common uses of rover robots. In the security field, several rover *droids* are being evaluated as guard replacements. They are equipped with motion-sensing detectors, infrared heat sensors, circuits that detect the noise of broken glass and other security related concerns. They generally are left to roam the grounds of a facility scanning for intruders. They are constantly in touch with a command station inside a building located close by. Any trouble that is encountered may immediately be reported by radio transmission. Several of these "nightwatchmen" are equipped with high-volume sound beepers that will effectively deafen would be attackers or render them helpless because of the pressure on their ears.

Advances are being made every day. Some day perhaps it will be difficult to detect that Old Charley of the midshift is in actuality a complex electromechanical android. Let's hope, though, that the designers of those systems don't allow themselves to incorporate real weapons among the subsystems.

Nightwatchmen and office-building rovers are becoming more commonplace. Insurance companies and other businesses have been profiting from the likes of the computerized mail carrier. These mailmobiles have been wandering down halls delivering interoffice paperwork for almost five years now. They come in various shapes and sizes, from the slender minibus look-alikes to the more familiar cylindrical R2D2-like physique.

Some have several "eyes" that track an invisible phosphorous trail or guideway that may contain instructions as to which places are stop points along the route. When these machines do stop, they generally sound short beeps to make their presence known to the secretaries in the area. After being loaded or unloaded they are free to wander on their merry way to the next office waystation. The period of time they are stopped at a site is automatically programmed into their control structure yet may be overridden by the use of stop buttons located on the body of the vehicle.

What happens if you are in the way during their trek down the hallway? Most of them employ rather sophisticated collision avoidance detectors that will result in the vehicle stopping several inches before the obstacle. Some even have override electronics that will allow them to inch up to an obstruction to nudge it out of the way. However, these nudges will cease if the object is immovable. These rovers are equipped with a large bumper in front like the AGV to guard against any personal injury.

Even though they seem to be more efficient, they will probably never replace the friendly chit-chat that accompanies the morning mail carrier. Perhaps a rover equipped with an intelligible voice synthesizer? Think of the conversation possibilities! It could recount to you its exciting encounter with the broom closet the previous evening!

Power for both these applications is usually supplied through a system of rechargeable batteries. The robots are brought out of service for some period of time to allow their batteries to reach a full charge. In the case of the security guard there would be shifts of vehicles much like a human fleet. The mailmobiles are not generally used at night and are usually recharged by plugging them into the ac power line, which also results in a savings because the electricity use rates are lower during those off-peak hours.

In this chapter we will use both these rover applications to explore the design of mobile robots. Throughout the following pages, various subsystems will be presented and the design philosophy explained. The following chapter will dwell on the software control aspects of the machines discussed here.

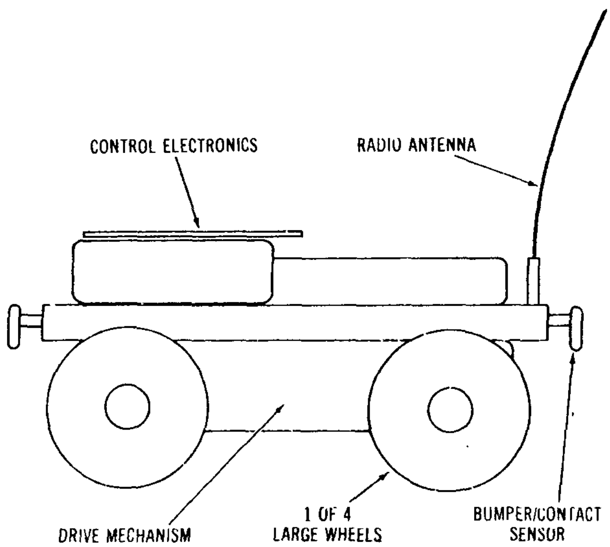


Fig. 1-2. Rendering of M1, remote-control rover.

MOTION SYSTEM'S DESIGN

As it is with anything, thorough planning is essential when designing an electromechanical system. In the building of a house, an architect first must plan the creation by developing a series of drawings called blueprints. In electronic systems a series of design specifications is written. It is here that we begin our exploration of the design of motion systems.

The architecture of the robot is much the same as that of a building. All the critical features and components are listed. In electronic systems the block diagram serves to show, at a glance, all the main parts of the circuitry. Before this diagram can be attempted, however, many things must be determined.

In an intelligent rover some consideration must be made as to whether or not it will require a microprocessor brain. Then, any on-board storage (memory) requirements are hashed out. Finally, the various input and output mechanisms are explored. Sound familiar? It should because that is the general way in which any microprocessor system is planned. But, is it the right way to plan a robot?

Looking at the overall plan for a roving robot design would help with its development. The following list depicts some of the characteristics of a security rover. Of course, the drive mechanism is included and the various electronic surveillance sensors are listed:

IMPORTANT CHARACTERISTICS OF A SECURITY ROBOT

- Three-Wheel Drive Mechanism
- Motion Sensor
- Infrared Heat Sensor
- Voice Output to Warn Intruder
- Radio Link to Base
- On-Board Intelligence
- Rechargeable Power Source

Notice where the mention of the brainpower comes? It is generally thought of as secondary. The drive is tantamount because it is the most impressive of its capabilities. The sensors are what makes it do its thing. The brain is simply there to tie those together.

After this assessment of the system, shouldn't we start with the I/O and slowly migrate to the processor? Not yet! Remember, as robot "architects," it is our job to first draw up specific specifications for each sub-unit within the entire system.

Here is where we go separate ways. The first application studied will be a remote-controlled rover. This system will be basically brainless (at least there will be no on-board brains). This type of system may be used as a police bomb disposal unit or even a no-thrills security drone that may be operated from a central guard station.

Fig. 1-2 depicts a typical system. I will call this M1 for Mobile 1. M1 has several features. The first of which is its four-wheel drive base. The rubber tires are somewhat deflated to ensure increased traction. Its top speed may be two feet per second, and it can vary this speed, proportionally, down to a slow crawl. The robot itself only measures 15 inches in length and weighs about 4 pounds. The weight is mainly attributed to its six C-cell batteries that power the base. These are rechargeable nickel-cadmium cells (nicads) that are mounted in a compartment in the undercarriage. The wheels are driven by gear motor systems that receive their commands as to direction and speed via RF carriers. The two front wheels steer 15 degrees in either direction proportionally, much like the speed control. Both controls come from the same radio receiver.

Feedback from M1 is in the form of a front-mounted collision bumper. When activated, a separate radio frequency is transmitted from the vehicle indicating a collision. This signal is sufficiently different from the received motion signals that no interference is possible. Both transmitter and receiver are mounted inside the body of M1. There are no other inputs or features.

What good does this remote-controlled base do us? You'll see later, just hang on.

The next application to be introduced is fondly called M2 (hard to come up with that name). In contrast, M2 has brains. In fact, there is very little that M2 does without the use of at least one microprocessor. Yes, I am talking about a multi-processor vehicle. This unit has only two wheels. They work on the principles outlined in the first volume when I described Milton Bradley's Big Trak®*. In fact, one of these bases is used in this experiment. A separate slave microprocessor is in control of these wheels. Its language is strictly "which direction" and "how far." It off-loads the main microprocessor of

*Big Trak is a registered trademark of Milton Bradley.

the humdrum chores of motion. There is another microprocessor dedicated to the ultrasonic ranging system. In this application, M2 can maneuver in rooms without getting lost or bumping into walls.

M2, like M1, is also powered by batteries located in the base. However, it also requires several other ones throughout the superstructure of the robot. The reasons behind this will be pointed out soon also. Is this starting to sound like a sales pitch? Actually, it is! I want you to start daydreaming about how these things are interconnected and why. That is what design is all about. We have only speculated on the design of each of these applications. There are no block diagrams as such. You see no schematics, no program listings, no parts lists. It is here that the concept of "imagineering" begins, and to be an effective robot designer you must have a great deal of imagination.

Design Specifications

Now we get back to earth. It's time to get to work listing actual specifications for each application. The place to start is to define a list of functional duties. For our security robot the following list spells out my desires. Notice that this list is quite a bit more detailed than the previous one. Here is the place to get your wishes in. You may find later that the duty you would like to perform is either too costly, too difficult, or even impossible.

DETAILED REQUIREMENTS OF A SECURITY ROBOT

- Drive Mechanism
  - Three wheels
  - Each wheel powered
  - Special traction tires
  - Proportional steering
- Motion Sensor
  - Ultrasonic ranger for distance to object
- Infrared Heat Sensor
  - Determination between man and other objects
  - Fire detection
- Voice Output
  - Highly intelligible
  - Canned phrases
- Radio Link to Base
  - High reliability
  - Voice and data
- On-Board Intelligence
  - Low power consumption
  - Performs simple, logical deductions
  - CMOS nonvolatile memory
  - Field-replaceable snap-in package
- Rechargeable Power Source
  - Gel-cell battery supply
  - Charger built into rover

The following two lists outline similar desires and functional duties pertaining to the mailmobile and the factory AGV-type applications.

DETAILED REQUIREMENTS OF A MAIL-HANDLING ROBOT

- Drive Mechanism
  - Four wheels
  - Two wheel steering
- Optical Path Sensor
  - Three-detector system
  - Follows path by straddling edges
  - Middle sensor detects stop points
- Ultrasonic Collision Sensor
  - Detects 2 feet in front
  - Slows vehicle to crawl
- Mechanical Bumper
  - Stops vehicle when activated
- Travel Override Switch Bar
  - Halts vehicle from resuming route
- Stop Point Annunciator
  - Beeper to signal stop point
- On-Board Intelligence
  - CMOS single-chip processor
- Rechargeable Power Source
  - Gel-cell battery
  - Built-in recharger

DETAILED REQUIREMENTS OF AN AUTOMATED GUIDEWAY VEHICLE

- Drive Mechanism
  - Four wheel
  - Two steerable wheels
  - Proportional steering
- Radio Guidewire Sensor
  - Two-coil type sensor and control.
- Mechanical Safety Bumper
  - Stops vehicle immediately when activated
- Automatic Warning Light and Bell
  - Lights and sounds when vehicle is in motion
- Radio Command Link
  - Separates command frequency link to controller
- On-Board Intelligence
  - CMOS controller links to sensors and radio
- Rechargeable Power Source
  - Lead-acid car battery

Where does the radio unit fit in? Hold your horses, that's a way down the road!

With the basic functions defined, it is time to put quantitative amounts on the wishes that will turn them into specifications. Determine how much that arm can lift, how fast variable speed is, and what type of microprocessor you have in mind. Start defining the size and shape of the robot. Its

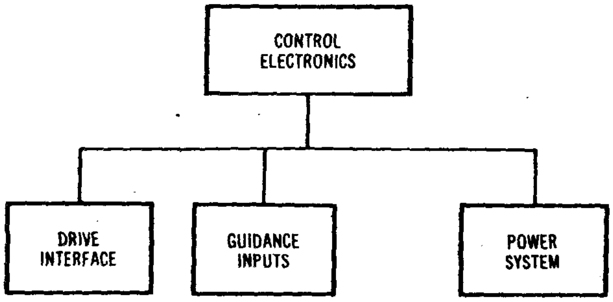


Fig. 1-3. Block diagram of a mail-carrying rover system.

weight is specified here and any power requirements. List them all. It will make the design process easier.

After this is complete you have about enough information to build a block diagram. This document shows the functional interconnections between sub-units in an electronic system. Normally the system block diagram is void of details. It may be as simple as showing a microprocessor, I/O, memory, and a motor interface. Don't make it too general, for then it would serve no purpose. I have laid out a general system diagram of the mail robot shown in Fig. 1-3.

Don't worry about my going through the robots too fast because I intend to go into the excruciating details of their design later.

As you can see in the figure, all the main functions are spelled out. There is no mention, however, of which type microprocessor or even details on any of the I/O circuits. Yet this is a specific diagram of a functioning mail-carrying robot. From here, a detailed circuit block diagram or block diagrams are done. The reason for the mention of more than one is that microprocessor brains for robots may require their own tiny system of various functions, as well as some of the I/O circuits. You will see later that the design of an intelligent motor drive interface can become as complex as a personal computer.

Drive Considerations

It's time to build our block diagrams for real. Using the hypothetical one shown in Fig. 1-3, the first block to be defined will be the drive interface. As I said before, this is the most obvious feature of a roving robot. It is also the one interface that must work before the rest of the system is operational. When considering a drive system, several factors are involved. I am not going to go over them in great detail because they are covered in Chapter 3 of Volume I. I will, however, revisit the principles of a two-wheel drive system.

Obviously, depending on the application, the drive mechanism of a particular rover may be entirely different. In our AGV application, a three- or four-wheel, conventional steering mechanism type system would serve the need. In the mail carrier this may also be true. The security robot may demand more control over rough terrain though. In this application, a treadlike arrangement might prove essential.

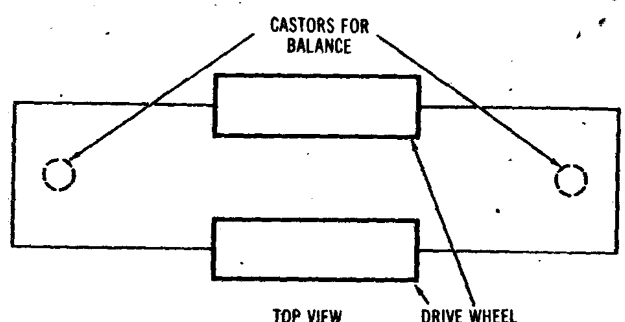
In the specific design experiments described as part of this chapter, I chose both a four-wheel and a two-wheel mechanism. The two-wheel type may sufficiently simulate that of a tread. Both are not industrial vehicles but scaled down working models that incorporate the same electronic systems design of the larger more powerful types in use today.

Let's get into the drive properties of both now, in order to complete the block. Fig. 1-4 depicts both systems used here. In Fig. 1-4B the four-wheel system uses two stationary wheels that are powered by a dc permanent magnet motor. Changing the direction of current through the motor effectively reverses it. The two front wheels are movable. They are allowed to pivot about a parallel axis 15 degrees in each direction. This will serve to guide the vehicle to the left or the right during motion.

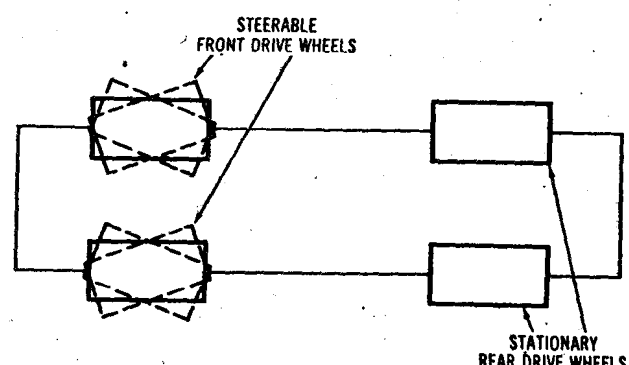
These two steering wheels are also powered to turn in the same direction as the rear ones. This gives a four-wheel drive effect. It increases drive traction and allows the vehicle to climb upgrades and traverse rough terrain.

The two-wheel drive mechanism uses a separate motor for each individual wheel. There is no common axle between wheels. Forward motion is accomplished (see Fig. 1-5) when both wheels are rotating in the same direction. Turning happens when one or the other motor is reversed. Refer back to this drawing throughout the discussions of M2's drive control circuitry.

A three-wheeled system would act in much the same way



(A) Two-wheeled drive.



(B) Four-wheeled drive.

Fig. 1-4. Mechanics of two drive systems.

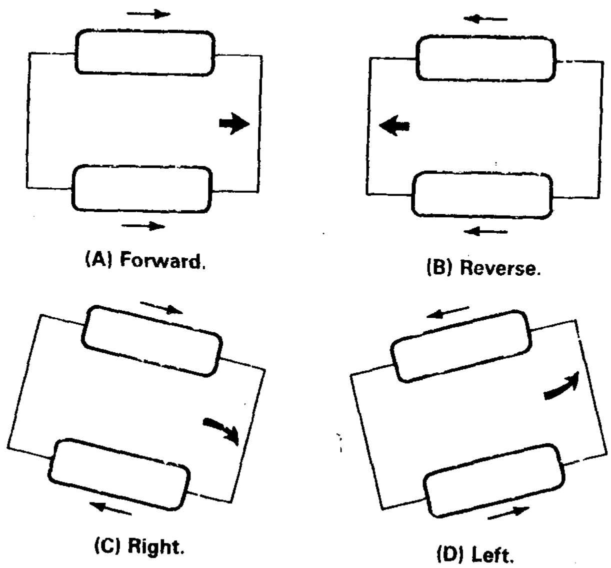


Fig. 1-5. Action of two-wheeled drive under varying wheel direction combinations.

as the four-wheeled design presented. It is not necessary, of course, to power that third wheel. Just use it for guiding the vehicle to the right or the left. Other forms of drive mechanisms exist. They are only limited by the imagination.

Pick the drive system that suits your application best and put it into the drive block in the diagram. Let's go on to the input section of the system.

Input devices for rovers can vary from bumpers that detect collisions to manual push-button switches used to delay the mail carrier a little longer. Basically, there exists a myriad of sensors that get attached to this input block. Also, here is where any thought toward a sophisticated guidance system begins.

Rover Guidance

Guidance of a moving vehicle is a very difficult problem. You're probably going to feel that this part of Chapter 1 will go on for three chapters. In actuality, the discussion will be broken up between this and the next chapter. Only hardware issues are covered in this chapter. The software used to guide vehicles is presented in the next chapter.

Let's assume that, for our purposes, guidance is the act of assuring that a vehicle reasonably follows a preset course or route. This course may be physically marked or constrained, or it may be completely invisible. The vehicle will, at some point, be given the possibility of finding this route, and it will have the ability to physically follow it. There are a number of ways to mark a route. Let's look at some of them.

The first is to simply draw, with a contrasting color, the route to be followed on the ground or flooring that passes beneath the vehicle. Another variation to this could be to paint an invisible line that only is detectable under certain types of lighting. This is similar to the ink that is used in some amusement establishments to mark your hand. They can tell if you have already paid for your ticket by shining a portable ultraviolet lamp over the area. There are several chemical solutions to accomplish this. The invisibility is used mainly where the route markings would appear unsightly as in an office environment.

If you're roving around a factory floor, there are even other alternatives. Standard single and double tracks are quite acceptable. The railroad train guidance system is obviously the most simple, as long as the train doesn't exceed a set speed limit. This might cause the momentum of the vehicle to push it off the guide track. If your workers find that those tracks get in the way, there are invisible tracks that can be implanted beneath the floor.

As discussed briefly before, an RF carrier is transmitted over these invisible tracks and is picked up by small receivers located in the vehicle. Depending on the strength of the signal, the vehicle will steer proportionately to the right or left. Through this system, a very accurate path control mechanism can be accomplished.

There are a few other methods of guidance being explored or used in industry. One is to use optical rangefinders located on the rover. Special reflectors are located in various places around the plant. Through triangulation the robot can find its position and make any corrections. A similar system uses three lasers located in corners of the plant. On the rover is a sophisticated rangefinder mechanism that detects the presence of these signals and computes its position by determining the phase relationship between itself and the beacons. We will begin to investigate the design of several of these guidance systems here but we will leave out the more exotic.

Optical Track Guidance—The method used by standard railroad cars for guidance is obviously the simplest implementation of keeping a moving vehicle on a predetermined path. Outside of this purely mechanical method, few approaches are as easy to design as that of the optical track.

As mentioned before, the optical track system is based on the detection of a painted line that is applied to the floor surface beneath the path of the moving vehicle. In the case where invisible paint is used, a special lamp will be used to illuminate and, therefore, detect the presence of the path.

There are several approaches that can be used to both detect and follow this painted line. All methods use the reflection of a beam of light off the surface of the path or adjacent to it. Fig. 1-6 illustrates the basic principles of this approach. A beam of light is transmitted from either an incandescent or solid-state lamp source in an angular direction toward the surface directly underneath the vehicle. The laws of light reflection show us that some portion of this beam will bounce off the surface and be deflected toward a similar yet opposite angle. It is at this angle of deflection that a mechanism is employed to capture the energy of this reflected beam. This

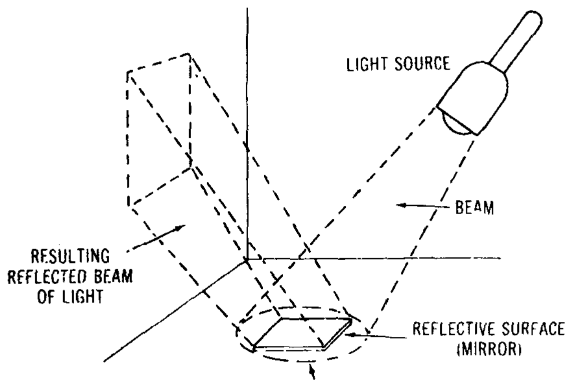


Fig. 1-6. Principles of reflected-light detection.

device may be one of several types of photocells, phototransistors, photodiodes, or even the somewhat outdated photomultiplier tube.

Because of the proximity between the floor surface and the emitter-detector pair, there will always be some amount of reflected light falling on the detector. The normal coating that is applied to the floor will reflect a given amount. If the painted line is reflective in nature (as in a metallic strip), then more light will be detected when the guidepath is encountered. Conversely, if the path is painted with flat black paint, then a lesser amount of light will outline the guideway.

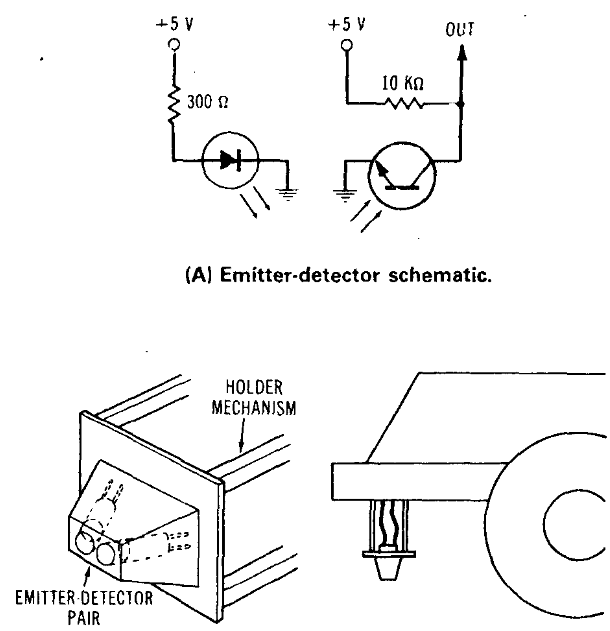
With these basic principles in mind, it is now possible to venture further into the control method of staying on the guideway once it's been detected. The first approach to study is the single-head method. In Fig. 1-7 a simple mechanical and electrical design is outlined. A vehicle is fitted with a guideway emitter detector, which is mounted in the front center of the vehicle. The amount of light reflected from the roadway is converted into a proportional voltage by a phototransistor (detector). This voltage is then applied to one input of a two-input voltage comparator; the other input is connected to a manually variable voltage source. When the vehicle is initially turned on, this manual level must be set up to provide a trip point for the comparator. With the detector not looking at the guidepath, the variable source is adjusted until the voltage from the detector equals that of the manual source (reference). At this time, the output voltage comparator will switch to an active state. Any significant change in the light energy detected will cause the comparator to change state indicating a not-equal-to condition between the two voltage sources. In this way, the guidepath is electronically detected. From here on, the control of a vehicle is relatively simple.

Fig. 1-8 shows a simple circuit that is used to control a two-wheeled base using the single-detector method. Following the drawing, we see that as long as the comparator output is not active (on guidepath) the wheels are connected for a steady forward motion. When the guidepath is lost, as in the case of a turn, what happens? According to this schematic, the vehicle backs up! Obviously, this is not an adequate approach. How will the control electronics know which direction to turn so that an encounter may take place once again with the path?

This is where a second detector comes in. It is possible, with a smarter electronics package, to utilize the single-detector method for guidance. However, at this time, let's stick to the simpler methods and leave the more complex for the next chapter when more program-oriented control is discussed.

When using two detectors, there are two methods that may be employed to mount them. One is to fix them so that their light beams will straddle the guidepath. The circuit in Fig. 1-9 shows this type of implementation. As long as the path is not detected, the vehicle goes forward. When the right detector sees the path, it turns the vehicle toward the right to straighten it out. The same is true for the left except, of course, the vehicle will turn to the left. This side-to-side travel may be reduced if the detectors are spaced to where they are very close to the path.

The other method of using two detectors involves having them on either edge of the path. Fig. 1-10 depicts the circuit, and the actions the vehicle takes when one or the other loses the path. As you can see this implementation is very similar to the single-detector method except it is now possible to detect which direction the vehicle is traveling in when a loss of guidepath is discovered.



(A) Emitter-detector schematic.

(B) Holder mechanism.

(C) Vehicle with sensor mounted on front.

Fig. 1-7. Mechanical details of a simple one-head optical guidance detector.

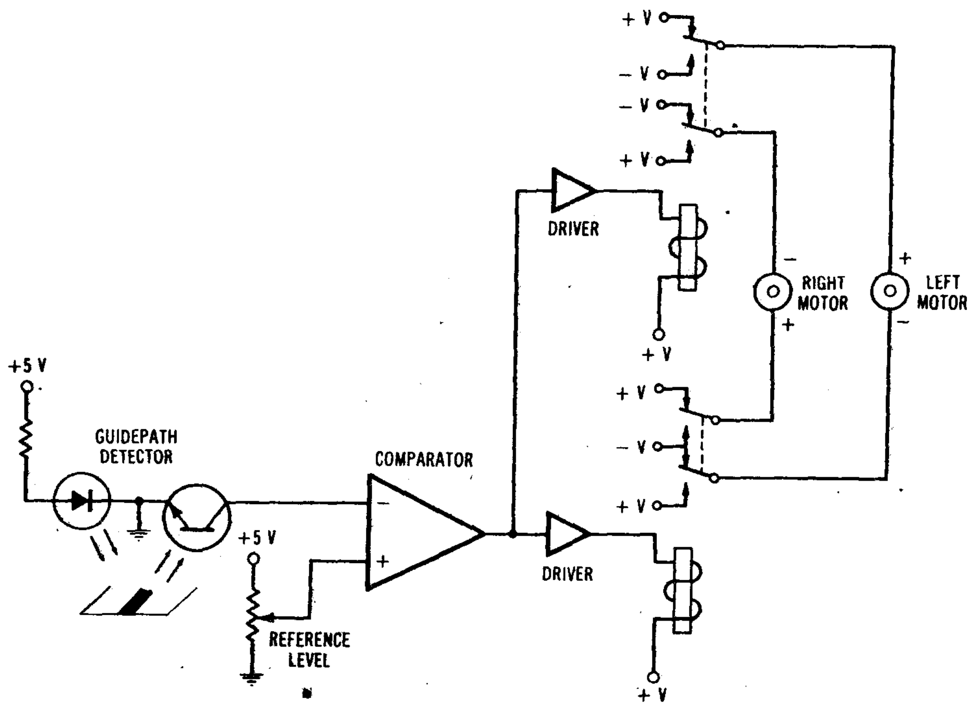


Fig. 1-8. Schematic diagram to support the design shown in Fig. 1-7.

In my experimentation I have found the latter of these two to be the most reliable. Some of the problems encountered with the straddle method were the fact that the change in direction of the motors, as a response to a detector change, was, in some cases, not sustained long enough to effect an actual physical change. In those cases, the vehicle would perform a slight jerk; however, once the detector cleared the path, it assumed that it was successfully straddling it again.

Another problem in all methods has been motor noise-tripping circuitry that enabled the relays at odd times. This can be solved completely by introducing a separate power source for the motors.

All the previously mentioned methods attempted to keep the vehicle straddling or on a painted guidepath. A reverse approach to this could be designed where the guideway is actually composed of two painted lines resembling a road with curbways! Fig. 1-11 spells out the particulars. In this

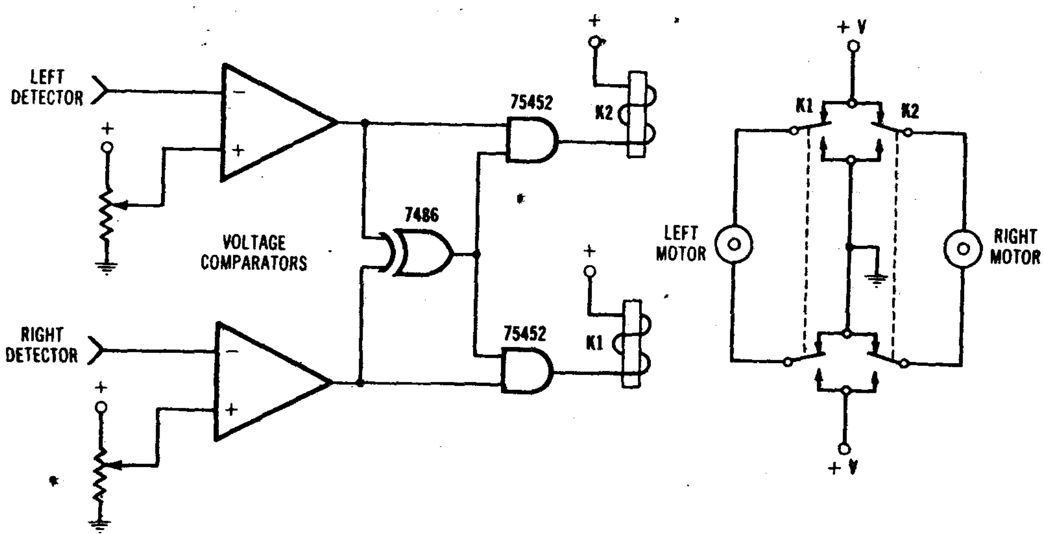


Fig. 1-9. Schematic diagram of a two-detector guideway system.

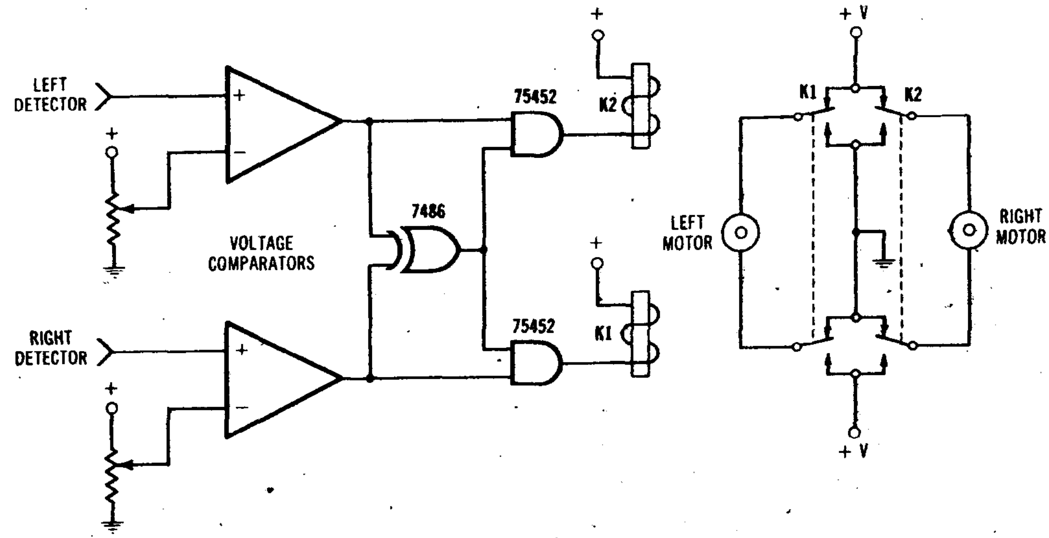


Fig. 1-10. Schematic diagram of a different method of implementing Fig. 1-9.

system the control electronics assumes that as long as both detectors see no guidefence, all is okay. When the right detector encounters the fence, it will switch directions of the left wheel to pull it foward the left, therefore, guiding it back on the path.

As you can see, there are several methods to guide a moving vehicle using light and a painted guidepath. In the case of the mail carrier, at certain junctions along the path instructions are embedded into the path. These commands tell the vehicle that this is a proper place to stop and announce itself. From that point on an electronic timer, within the workings of the rover, takes over to determine how long to stay there. As mentioned before, several manually operated halt switches may be located around the perimeter of the vehicle through which this time may be extended.

The information coded into the guideway is usually done as a series of short guideway "gaps." These are actually areas of the painted path that are void of paint. A special information gathering detector is mounted in the front center of the vehicle to read the path for these gaps. If you liken the guidepath to a series of painted stripes like those found on the side of a grocery product box, the approach becomes clearer. Although the information provided underneath these vehicles is seldom of that complexity, it could be possible to use the exact or a derivative of the Universal Product Code.

You may have noticed, if you have read the previous volume in this series, that optics plays a big part in the field of robotics. Here, we have just begun to touch on the application of light guidance systems. The painted path is by far the simplest. Others involve triangulation techniques much like

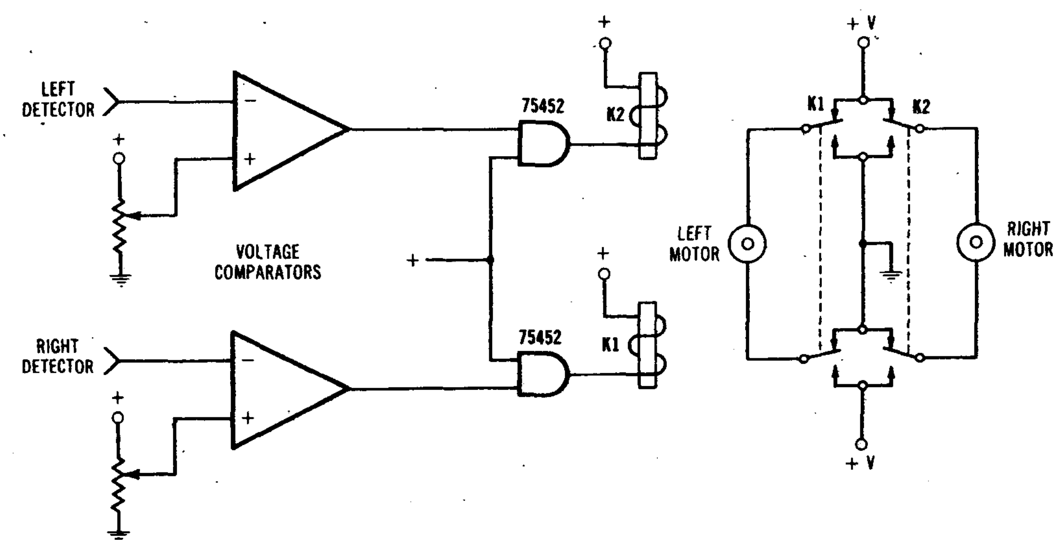


Fig. 1-11. Schematic diagram of a two-detector guidefence system.