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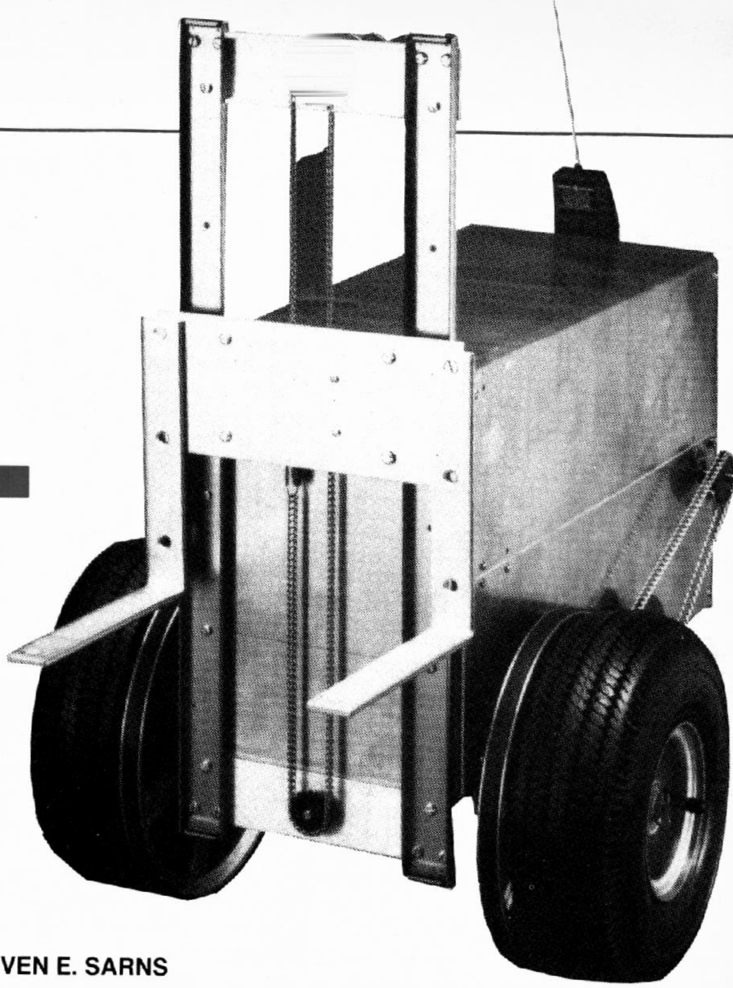

R-E ROBOT

This month, we add the first of the R-E Robot's sensors—an electronic eye.

STEVEN E. SARNS

Part 12

AT THIS POINT, OUR robot is an efficient tractor unit, moderately intelligent, with plenty of pulling power. He can carry items from place to place, and can understand complex instructions. However, he is also as blind as a bat. To make the unit as useful as possible, we must give it a way to see.

You can fully appreciate the severity of the problem by imagining the following example: You are at the end of a hallway. Several doors can be chosen. Look carefully, close your eyes and, without touching or peeking, walk forward and turn into a doorway.

That is what we were asking the robot to do when we programmed the MAILBOT example in Part 9 of this series (**Radio-Electronics**, August 1987). Instructions like "Go forward 10 steps, turn right, and then go forward again 10 steps" seem clear enough on paper, but what if you did not turn exactly 90 degrees? What if your steps were short for some reason? Worst of all, what if you lost your bearing and had to start over, all without peeking?

To make it easier for the robot to get around, we will give it the ability to detect and track light sources. That capability will allow the robot to follow a light beam or an optical stripe on the floor.

Ideally, we also would like to provide the robot with the capacity to determine the distance to a light source and to triangulate its position using several light sources. Unfortunately, the software required to perform those last two tasks is quite formidable, and at this time is far from being fully developed. For now, we will discuss the problems involved in giving the robot those capabilities, and the hardware needed to input the data that future software will require.

The robot eye will eventually be mounted on a rotating platform, or "head." The head will contain the electronics for a number of the robot's sensors and will be discussed in more detail in the next installment of this series. The head will move the eye through a few degrees, mapping light intensities at several points. The data collected in that way will be used by all of our navigation schemes.

Navigation schemes

The navigation scheme that we will implement now permits the robot to track a light beam. The robot will rotate the eye until a light-intensity maxima is determined. The robot will then angle toward that maxima.

For the future, position-finding is merely an extension of that navigation technique. By mapping the maxima of several known light sources, the robot can determine its position fairly accurately using triangulation.

For range-finding, we will need to add a second eye to the head. Then, the robot can use parallax to determine the distance between it and an unknown light source. The parallax principal, in which the difference in viewing angle at two points that are equidistant from the third are used to determine the distance to that point, is what provides humans with depth perception; the two equidistant viewing points are our two eyes. See Fig. 1. Note that the technique is only good at relatively close ranges. But remember that even humans lose their depth perception at distances beyond 30 feet.

The human eye

In terms of design, the human eye is difficult to match. The spectral response is not too wide, ranging from 360 to 780 nanometers, but color is of secondary importance to other factors. The eye is capable of resolving details as small as one minute of arc ($1/60$ of a degree). And most importantly, the eye can operate in a very wide range of light intensities, ranging from star-lit night to bright sunlight. If those light levels are quantized, you will find that the range is on the order of 180 dB, or a billion to one.

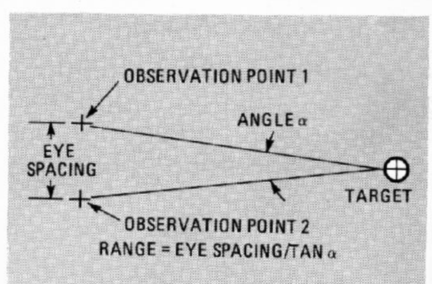

FIG. 1—USING PARALLAX to determine the distance to an object.

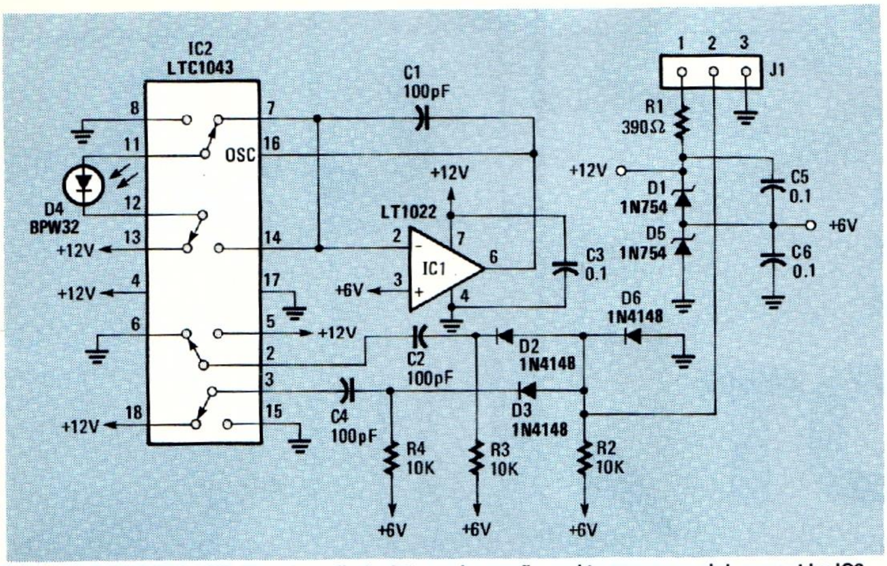

FIG.2—THE ROBOT'S EYE. The photodiode, D4, can be configured to source or sink current by IC2.

The robot eye

Our design goal was to make the robot's eye useful over as wide a range of light conditions as possible. While it is unlikely that you will need to have the robot navigate by starlight, giving the robot low-light capabilities will increase its distance range. Since light follows the inverse square law, that is, the illumination is inversely proportional to the square of the distance, light levels fall rapidly as you move away from the source. At the same time, operation at conventional ambient light-levels must be possible, and the robot should be able to deal with most common light sources.

Therefore, we feel that the minimum acceptable range should span at least 4 orders of magnitude (10,000:1 or 80 dB); that corresponds (using the inverse square law) to tracking an ideal light source over a 100:1 distance range. The maximum possible dynamic range using readily available components is about 120 dB. That corresponds to a light range of 1,000,000:1, or a distance range of 1000:1.

We choose .01 lux as the lowest light level that we wish the sensor to respond to. A lux is the amount of light falling on one square meter from a candle located one meter away. That is at the extreme low-end of most detectors so to improve performance we will enhance the unit's light-gathering power with a Fresnel lens. Focusing a 4-square-inch Fresnel lens will amplify the light level by a factor of 100. If we were to focus such a lens on the sensor, a light level of .01 lux at the lens will result in a light level of 1 lux at the sensor. Most detectors can work with such a light level.

As we mentioned earlier, future range-finding requires that the robot be equipped with two eyes. Those will be mounted 10-inches apart on the head. If the robot can locate a light source to within 5 degrees of arc, that spacing will allow range finding at distances of up to 30 feet.

TABLE 1

Light Level	Photodiode Current
10,000 lux	100 μA
1,000 lux	10 μA
100 lux	1 μA
10 lux	100 nA
1 lux	10 nA
0.1 lux	1 nA
0.01 lux	100 pA
0.001 lux	10 pA
0.0001 lux	1 pA

Selecting a sensor

Many different sensors for measuring illumination are available. Phototransistors, photodiodes, and PIN photodiodes are all common and well understood.

If our prime design criteria is dynamic range, then we must choose the device with the largest sensitivity range. The key parameter in determining a unit's sensitivity is its *dark current*; that is the leakage current that flows when no light reaches the device. In general, photodiodes have the greatest ratio between dark current and high-illumination output. One, the Siemens BPW32 has a rated dark current of less than 10 pA and a high-level output at 10,000 lux of 100 μA. Those figures represent a dynamic range of 140 dB. Typical output currents of that photodiode for various light levels are shown in Table 1.

Note that the photodiode's output current becomes non-linear above 1,000 lux and below .001 lux. Also, remember that linearity can also be affected by the supporting circuitry. If you can not locate the Siemens component, a suitable substitute is NEC's PH201A photodiode.

PARTS LIST

All resistors are ¼-watt, 5%
R1—390 ohms
R2–R4—10,000 ohms
Capacitors
C1, C2, C4—100 pF, ceramic disc
C3, C5, C6—0.1 μF, ceramic disc
Semiconductors
IC1—LT1022 op amp (Linear Technology)
IC2—LTC1043 IC switch (Linear Technology)
D1, D6—1N754 Zener diode
D2, D3, D5—1N4148 diode
D4—BPW32 photodiode (Siemens)
Other components
J1—male header
Miscellaneous: Fresnel lens, PC board, wire, solder, etc.

The 2.3-inch Fresnel lens can be ordered for $10.00 each, plus $6 postage and handling, from Edmund Scientific Company, 101 East Gloucester Pike, Barrington, N.J. 08007, (609) 573-6250. The part number is E32,589. NJ residents must add appropriate sales tax.

A bare printed-circuit board for the eye can be obtained from Vesta Technology Inc., 7100 W. 44th St., Wheatridge, CO 80033, (303) 422-8088, for $19 each. An assembled and tested eye PC board, Fresnel lens not included, is available for $59. CO residents must add appropriate sales tax.

The circuit

A schematic diagram of the eye circuit is shown in Fig. 2. The BPW32 photodiode, D4, provides an output current that is proportional to the illumination level. That small current will span a range of 10 million to one. If we were to convert the current into a voltage and the voltage into a binary number with an analog-to-digital converter, we would need a 23-bit unit! For example, if the full-scale voltage was 5, then the least significant bit would be 5 microvolts. Such a unit, if you could find one, would cost thousands of dollars.

Instead, we will convert our current into a frequency and use the RPC (*R*obotic *P*ersonal *C*omputer) to determine the period of the frequency. That will give us the dynamic range that we need, since a 140-dB range can be accommodated using a frequency band of 0.1 Hz to 1 MHz. The circuit will output approximately 200 kHz when held 3 inches away from a 60-watt light bulb in a reflective lamp. The circuit will output 0.5 Hz when illuminated by the trace of an oscilloscope 2 feet away.

The frequency range used is critical. The eye must rotate a small amount, take a reading and repeat the process continu-

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ously throughout a full 360° rotation of the head. Under low-light conditions the output of the eye will be a low frequency. If the eye is operating at 1 Hz and light readings are taken every 5°, it will take over a minute to rotate the head. Obviously, then, the higher the frequency output of the eye, the better. We can always divide the frequency down to get it in a range that the RPC will be able to process effectively; however, we cannot multiply a low-frequency input to obtain information faster.

The active integrator used in the circuit is based on a simple, classic design. The photodiode's output current is used to charge a capacitor; the charging time, of course, is the integral of the input voltage. A novel twist, however, is that we will use the photodiode to both charge and discharge the capacitor. A newly developed IC from Linear Technology Corporation, the LTC1043, will be used to switch the photodiode from a current-sourcing to a current-sinking configuration. That IC is also used to convert the output of the integrator to a frequency signal for input to the robot's RPC.

The integrator is built around op-amp IC1, a Linear Technology LT1022. That op-amp is chosen for its high-speed operation, modest input-bias current, and low cost. Other operational amplifiers can be substituted, but be aware that any increased input-bias current will degrade the low-light performance, and decreased output slew-rate will degrade high-light-level performance.

Construction

The PC-board's design is somewhat different in that all of the components except J1 are mounted on the *foil side* of the board; the PC pattern can be found in PC Service, and the parts-placement diagram is shown in Fig. 3. The components are mounted in that way so that the PC board can be used as one side of a light-tight structure supporting the Fresnel lens as shown in Fig. 4. Placing the traces on the inside of the box protects them somewhat from contamination; over time, that contamination can build up on the circuitry and affect performance. The completed board can also be covered with a conformal coating (that's a coating that closely conforms to the surface that it is applied to) or potted to minimize any contamination problems.

The printed circuit board is 2.3 inches by 2.3 inches. Those are the same dimensions as the Fresnel lens available from the supplier mentioned in the Parts List. Use screws or standoffs to mount the lens 1.3 inches from the photodiode. That is the

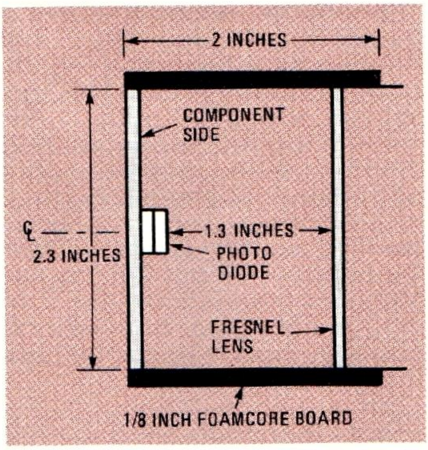


FIG. 3—ALL OF THE COMPONENTS, except J1, mount on the foil side of the PC board.

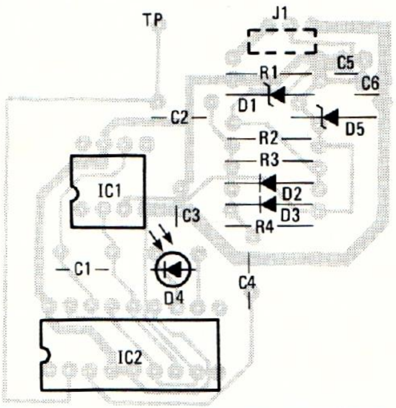


FIG. 4—A FRESNEL LENS is used to concentrate the light on the photodiode.

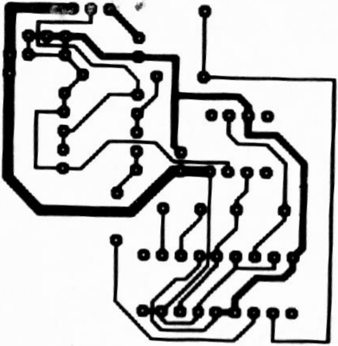
focal distance of the lens and will result in maximum light gathering power. To fine-focus the lens, attach an oscilloscope to the photodiode and, with the eye pointed towards a light source located several feet away, adjust the lens supports for maximum frequency output. If you find that your eye saturates too quickly, you can simply defocus the lens slightly to reduce the light level that reaches the photodiode.

After the lens has been focused, cut and mount the remaining sides of the box. Cardboard or a similar material is suitable for that; the author used Foamcore board, which is available at art supply stores. Hot-melt glue is a handy means of attaching the sides.

Paint the cardboard sides black to reduce the amount of light entering the eye except through the lens. That won't do much to stop infrared light, however. If interference due to infrared noise becomes a problem, laminate a layer of aluminum foil to the sides.

Next time

That completes the eye's construction. Now it's time to hook it up and test it. Unfortunately, at the moment there's nothing to hook it up to. That shortcoming will be taken care of next time when we show you the robot's rotating head. **R-E**



2.3 INCHES

THE ROBOT EYE'S PC board is shown here. Remember that the components mount on the foil side.