Then and NOW

ROBOT SENSORS

by Tom Carroll

Sensors are a very critical part of any robot, whether autonomous or teleoperated. Sensors are the robot's contact with the outside world or its own inner workings. There was a time when 'sensors' for an experimenter's robot were just a few whiskers connected to microswitches to sense walls and such. When the robot banged into a wall or obstacle, the switches were tripped and its simple logic steered it in another direction. I mentioned such a crude robot that I built years ago in last month's column. Certainly some early machines used photo tube, selenium, or cadmium sulfide cells to detect light sources and react accordingly, but sensors for the most part were some sort of bumpers or whiskers to detect tangible objects and barriers.

Those were the days before microcontrollers were available that could make sense of a suite of sophisticated sensors that we have available today. A typical robot emerging from the workshops of *SERVO*'s readers might have upwards of 100 sensors to guide it about its daily activities. Sensors can be used to sense the robot's environment or its own internal parameters. These might include active and passive IR sensors; sound and voice sensors; ultrasonic range sensors, positional encoders on arm joints, head and wheels; compasses, navigational and GPS sensors; active and passive light and laser sensors; a number of bumper switches; and sensors to detect acceleration, turning, tilt, odor detection, magnetic fields, ionizing radiation, temperature, tactile, force, torque, RF, UV, video, and numerous other types.

Figures 1 through 4 illustrate just a few of the industrial quality sensor types manufactured by SICK, a company who supplied many of the sensors used in DARPA's Grand Challenge. There are many similar companies producing sensors for use on robots.

IR Sensors

I'll start with IR sensors as they are among the most popular for experimental robots. Infrared sensors are usually divided into two basic types: the passive or PIR sensors that emit no IR radiation and the active types that emit an IR beam that is again detected by reflection. We all have used the PIR types to detect the presence of a human outside our homes and have it turn on an outside light for a specified number of minutes. Since hundreds of millions are sold each year for security purposes, the prices are quite low. The PIR sensor uses a crystal of lithium tantalate ($LiTaO_3$), a compound that possesses unique pyroelectric properties in that it can sense the temperature range of a human being's body. The crystal does not detect the actual temperature but a change in temperature. It does this by seeing a series of images focused upon the crystal by a row of Fresnel lenses as a person (or animal) crosses the viewing path. This crossing movement causes a series of images to cross the crystal's surface, thus, a succession of temperature changes in the crystal's charge status. Open up a typical outdoor security light fixture and you'll find a PIR sensor like in Figure 5 — the heart of the 'warm body' detector.

To detect a non-moving warm image, an image 'chopper' with wide teeth like a gear can be used to interrupt the image and cause the crystal to detect a series of changes in charge status, just like the Fresnel lens

Figure 1. Color sensors.

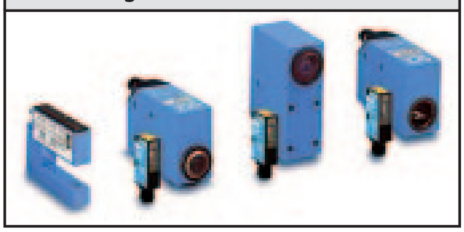

Figure 2. Distance sensors.

Figure 3. Photoelectric sensors.

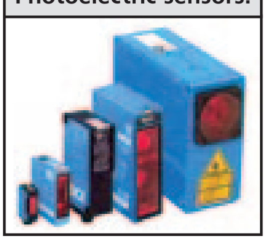

Figure 4. Inductive, magnetic, and capacitive sensors.

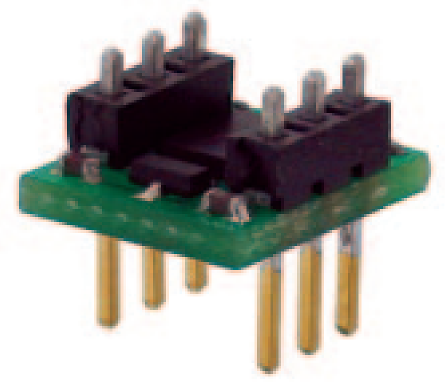

Figure 6. Parallax Hitachi compass.

array with a moving warm object. Check this technology out on Google; it's quite interesting. Passive IR sensors can also be used for two-way control and communications from a laptop computer or a hand-held remote control. They actually become active when they send a signal back to a computer or another robot.

The active IR sensors generally use an IR LED emitting an invisible beam that is, in turn, picked up as a reflected spot on a wall or object by a photo transistor. This same technology can be used as a range finder by having a focused beam emitted from the side or front of the robot at an angle and another series of IR detectors mounted behind a lens pointing straight out. The further away the sensed object, the greater change in detected angle by the detector array. You can try this out with a laser pointer held at an angle as you close in on a wall. If the laser is pointing to the right at, say, 45 degrees, the spot will move to the left as you get closer to the wall.

Lasers are particularly adaptable to robot ranging and object detection. The very inexpensive diode lasers available as pointers and power tool line generators make great robot add-ons. I have seen very cheap (under $5) builders levels with a built-in laser with a line generating lens at Harbor Freight Tools. This straight line projected onto an object and observed from above the laser can determine the shape of the object by some fairly simple edge detection software and a cheap camera. Lasers also generate a collimated beam that does not require a lens assembly to produce a small spot of light.

Figure 5. PIR sensor.

Positional Encoders

Positional encoders are probably the second most popular sensor on a robot. Most experimental robots do not have arms and do not use positional encoders to determine the positions of an arm's different joints. They do use shaft encoders on the wheels or motor shafts to determine the number of revolutions of the wheels and thus, the distance traveled by the wheels.

These encoders can use electrical contacts, magnetic Hall-effect detectors, or the more popular optical path broken by rotating teeth or opaque and clear graphics etched on a wheel. Absolute encoders output a binary word for each incremental position and are complex and expensive. Incremental encoders provide a pulse for each increment of shaft movement. The use of two optical channels enable the determination of the direction of rotation. Again, Google these unique devices for detailed information.

The use of potentiometric encoders is popular for the model aircraft servos (before hacking) and are used for 180° or less rotation. Multi-turn pots, partial turn pots, linear pots, and even trim pots can be used as feedback positional sensors. A 25 turn trim pot can be attached to a 25 turn leadscrew and hacked model airplane servo and be used as the feedback device for a fairly powerful linear actuator.

Compasses and Navigation Sensors

I tried to use a standard Boy Scout type of compass in one of my early robots to determine direction. It was one of those liquid filled types that dampened the moving disk that contained the tiny magnet and the north arrow. I pulled it apart so many times to place reflective stickers on the disk that it always leaked and the disk seemed to never point north as it was overloaded by stickers that eventually floated off the surface. It was so sluggish and my crude CdS and flashlight bulb detector array didn't work very well. Needless to say, I soon scrapped this robot compass (*but what a clever idea! - Ed.*)

Much better electronic compasses are available today for the experimenter. Magnetometer and fluxgate compasses began to be available to the experimenter in the '80s and first saw uses in consumer automobile compasses. These devices made autonomous navigation possible for the first computer-controlled machines. However, it was the inexpensive compass modules made by Devantech, Parallax, and others that made interfacing compasses to microcontrollers so easy. As Parallax states: "This compass module made exclusively by Parallax is a dual-axis magnetic field sensor built around the Hitachi HM55B IC. Parallax has made this compass IC accessible by providing Hitachi's surface mount sensor chip with a 3V onboard voltage regulator and resistor protection, all in a 0.3" wide six pin DIP module. The Hitachi HM55B compass module is compatible with the BASIC Stamp's 5V supply and signal levels. Acquiring measurements from the module is made easy with a synchronous serial interface, and even easier with the BASIC Stamp 2 commands SHIFTIN and SHIFTOUT." (See Figure 6.) I've used this one as it is quite small and easily placed in small robots.

Devantech uses a magnetic field sensor as the core of their device and states that "This compass module has been specifically designed for use in robots as an aid to navigation. The aim was to produce a unique number to represent the direction the robot is facing. The compass uses the Philips KMZ51 magnetic field sensor, which is sensitive enough to detect the Earth's magnetic field. The output from two of them mounted at right angles to each other is used to compute the direction of the horizontal component of the Earth's magnetic field." (See Figure 7.) Both of these devices are available from many of the advertisers in *SERVO* and *Nuts & Volts*.

Ultrasonic Range Sensors

Back in the '80s, Polaroid developed an automatic focusing camera that used an ultrasonic range sensor (transducer) to focus the camera's lens on an object, usually a person. I bought one, not to take the fairly expensive instant pictures, but to hack it. After getting into it a bit, I decided to not completely ruin it so I ended up using it as a camera. It piqued the interest of other experimenters also who soon saw many uses for the technology and Polaroid was quick to serve this unique market. They began marketing an experimenter's kit that contained two of the electrostatic transducers, an electronics board that was developed for the camera with a separate LED distance readout, and several flat 6V battery packs. I was fortunate to be given two of the kits by Polaroid to experiment with. (Actually I was accidentally given four, but that's another story!)

The transducers and drivers required a high current pulse, too high for AA cells, so Polaroid also developed a higher current flat battery pack that was behind each film pack. These range finders found their way into almost every robot that was marketed in the '80s. The October '00 issue of the *Seattle Robotics Society's Encoder* featured an article by Dennis Clark entitled "SONAR as I Have Done it" on the hacking of a Polaroid camera for the sonar module and transducer.

Figure 8 shows the uniquely shaped circuit board in the camera and the transducer on the table. A bit of a warning if you ever start playing with one of these — there's a pretty high voltage, like 300 VDC within the module that will certainly wake you up if you touch the wrong areas. I have been awakened a few times in the past. Newer units by other manufacturers use piezoelectric transducers that are a bit smaller.

Sensors for Toys

I have taken *Design News Magazine* for many years, an excellent source of mechatronics ideas for engineers, and the April 30th edition had a supplement highlighting sensors for toy design. We sometimes dismiss toys as low-cost, low-quality products just for kids to play with and eventually tear up, but toy manufacturers have come up with some of the most unique and complex things for just a few dollars. Such is the case with the Zig Zag Zog UFO Saucer featured on the front cover of the "Sensors ... in Toy Design" supplement of *Design News* (see Figure 9).

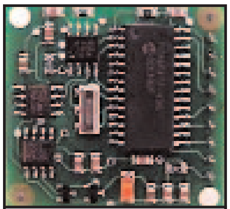

Figure 7. Devantech compass module.

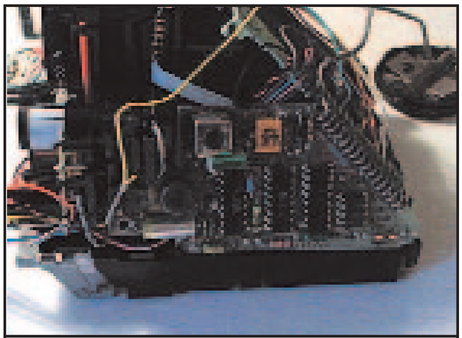

Figure 8. Hacked Polaroid camera sonar.

Designed for toddlers, I know that this $30 toy will be purchased, disassembled, and hacked by any number of adult robot experimenters before spring is over. The objective of the toy is for the little alien to try to avoid being captured by a toddler utilizing three IR sensors to detect obstacles in its path and two more IR sensors in its head to detect the kid trying to bop it there. If it is caught, the toy operates at successively higher speeds to avoid capture.

NEC's PaPeRo Personal Robot

The large Japanese company, NEC, recently brought a personal robot to the market — the R-100 called PaPeRo through its Personal Robot Research Center. There is no mistaking that this machine is of Japanese origin as it's a bit too cute for most adults but the technology is amazing, as is the case with most Japanese robots. Just as with Sony's Aibo — rest its soul — this robot has all types of sensors strewn about its body to assist in its interaction with humans. Voice and video image (people) recognition are among its most noteworthy. Figure 10 is a chart of some of its sensors. It may look like a cute toy, but it is anything but.

Figure 9. Zig Zag Zog UFO saucer.

Various Other Sensors for Robots

There are hundreds — if not thousands — of types of sensors made today to sense virtually any type of phenomenon you can think of. Besides some of the ones that I delved into, one type that I've used on several occasions is the Figaro gas sensor. Back in the early '70s when I first heard of it, the Figaro gas sensor was used to detect — you guessed it — gas vapors. The company has evolved it line of sensors to detect virtually all types of anything that can be sensed as a vapor. The sensing surface is made of sintered metal oxides of various ratios and metals according to the type of gas to be sensed.

The surface's conductivity changes according to concentration of the gas when reducing gases are absorbed on the sensor's surface. These sensors can detect alcohol in one's breath, propane, HVAC air, gasoline vapor, natural gas, and even cooking smells.

Figure 10. PaPeRo sensors.

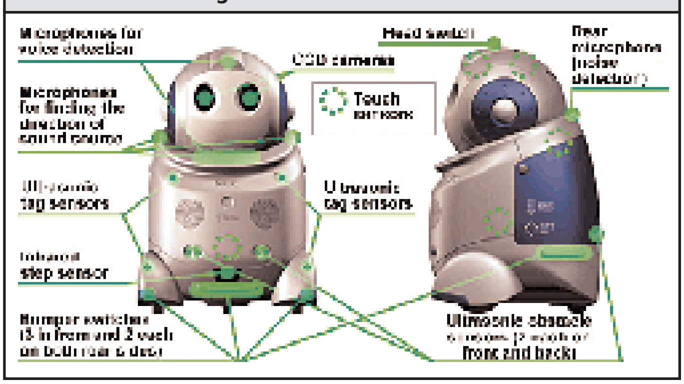

Figure 11. Figaro gas sensors.

Figure 11 shows a few of the gas sensors available today.

Temperature is easily determined by a simple thermistor, a resistor that changes resistance according to temperature. Atmospheric pressure and other weather-related phenomena can be determined from home weather station components. Smoke detectors are very cheap and great add-ons for a home security robot. Accelerometers and gyro systems are available from *SERVO* advertisers and model helicopter suppliers. Cheap GPS receivers abound and are great for longer-range outdoor robots. Radiation detectors can be used for high security robots. There is no limit of what type of sensor you can place on a robot.

If you want to know more about the hundreds of types of sensors available on the market today, visit the Internet and Google through millions of sites. A book I highly recommend is H.R, 'Bart' Everett's *Sensors for Mobile Robots — Theory and Applications*. This 1995 book still has a great amount of information that is applicable for today's experimental machines and is written by one of the world's most respected robot designers and builders. Bart has built a series of robots that are second to none, especially when it comes to sensor technology. **SV**

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