A COMPUTER CONTROLLED SENTRY ROBOT

A Homebuilt Project Report

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My robot's primary function is to randomly patrol a household while checking for fire, smoke, flooding, and intrusion, and take appropriate action if any of these conditions are found. It is appropriately equipped with numerous sensors, while still others are being planned. (Of highest priority is a tracking system that will allow the robot to follow a wire hidden beneath the carpet. This will make the repeated patrols a more orderly process.) To conserve battery power, patrols are made at random intervals. The robot spends most of its time in a passive intruder detection mode, where it actually has more available sensory inputs than when in motion.

A secondary purpose of this robot system is to serve as a mobile platform for research and experimentation in the areas of artificial intelligence, computer interface techniques, speech synthesis, and mechanical design. A SYM-1 single-board computer, mounted at mid-height on the front of the unit, forms the heart of the electronics. It functions primarily as a dedicated controller, but can be connected to a Synertek KTM-2 terminal through an RS-232C connection, thus greatly expanding the practicality of the overall setup. The robot remains motionless beside the terminal stand while the SYM-1 is connected to the KTM-2 terminal. The RS-232C connection provides both a power and data connection to the robot. When the robot is disconnected from the terminal, it proceeds under its own control on power supplied by a 12 V utility Die-Hard battery.

The mobile platform is equipped with numerous collision avoidance systems, including tri-directional sonar (forward, left, and right), four infrared proximity detectors, feelers, and, as a last resort, impact sensors. The data made available by these sensors is analyzed by the processor and the best course of action taken.

When not connected to the terminal, the robot has two modes of operation: passive and alert. In passive mode, the majority of sensors are activated but a good deal of the interface circuitry is powered down to conserve battery power. The robot relies on visual motion detection, ultrasonic motion detection, and hearing, to detect an intruder, while at the same time monitoring for vibration (earthquake), fire, smoke, toxic gas, flooding, etc. Some of these inputs are hardwired to cause an alert (switch from passive to alert status), whereas others must be evaluated first by software, which may trigger an alert if required. In the alert mode, all systems are activated and the robot is ready to respond to input information, or go on patrol. Either mode can be in effect while recharging, and recharging can be temporarily suspended if conditions warrant (what good is a watchdog that doesn't bark while he's eating?).

Recharging is handled automatically. The 12 V, 20 amp-hour battery provides approximately ten hours of service, and then requires about fourteen hours to recharge. Roughly one hour of power is available in which to locate the charging station (by means of a visual homing beacon) after the battery monitor circuits detect a low battery condition. The robot does not always wait for a low battery warning before returning to the recharging station. After a patrol, it may simply return to the recharger and wait until it's time to start another round.

The software is structured around a central loop that controls branching to various behavior pattern subroutines, which in turn call various library routines (such as sonar, speech output, time delay, steering, etc.) that can be used in many different routines. When the robot first starts from an off condition, each of the subsystems is automatically powered-up and tested. Voice output is used to announce the completion of each test.

To avoid the appearance of canned response to a given input, various signals are used to randomize behavior. For instance, the day of the week is represented by a 3-bit binary

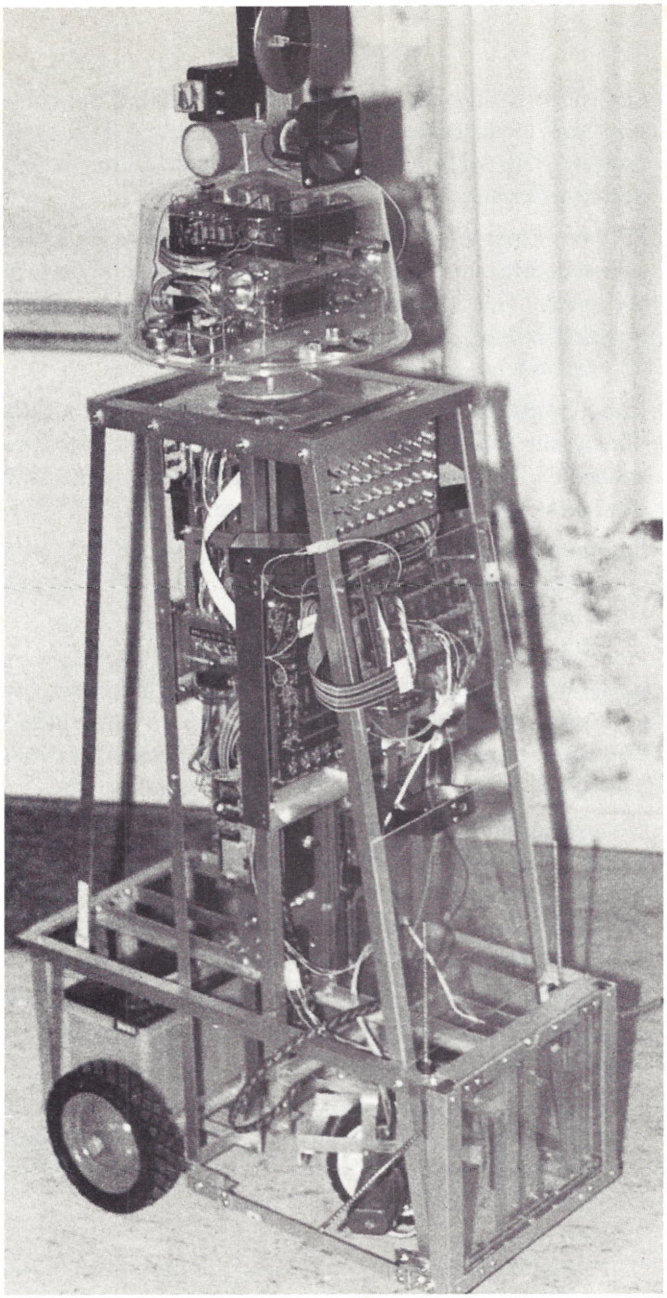


Photo 1: Overall View. Here is a full vertical view of the Robot assembly. The head sensors are for avoiding obstacles, animals or people. In this photo the newly added speech synthesizer is barely visible. A sonar transducer is mounted in front of the plexiglass panel. The ribbon cable wrapping around the right front frame member goes to a temporary EROM evaluation board. At present the Robot is a bare chassis without any formal attempt at making a finished, smooth housing.

number, and another bit tells the processor whether it is morning or night. By reading these bits before responding to an input, the response can vary according to conditions. A greeting of "Hello" in the morning could become "Hi" in the afternoon, for example. But this pattern is too easily detected. A more subtle variation would be to logically OR the AM/PM status bit with another piece of information, say the second bit of the day of the week, and use the result to decide which response to make. A random-number generator is also used to accomplish a similar result, both in speech synthesis and collision avoidance routines, giving the robot the appearance of having a mind of its own. The possibilities offered by software control of a system that is this complex make it an ideal platform for research and experiments in the field of artificial intelligence.

Processor Inputs

The robot uses many different sources of information to decide a course of action. Because I wanted to use this robot as an experimental platform, I provided a wide variety of sensors. The following list details those sensors that are currently connected to the robot, along with others that are still in development.

AM/PM: A single bit used to indicate morning or evening. It also drives a day-of-the-week counter.

Day of Week: A 3-bit binary code indicating the day.

Ambient Light: Signal for photocell on top of the head, which indicates if the room is light or dark.

Temperature: Two temperature sensing probes alert the processor if temperatures inside or outside the robot shell exceed or fall below predefined values.

Smoke: Photoelectric smoke detection circuit.

Toxic Gas: Figaro toxic gas sensor and detection circuit indicate presence of carbon monoxide, butane, propane, methane, etc.

Fire: Infrared fire detector acts as a back-up for the mechanical heat sensor.

Vibration: Seismic monitor indicates presence of vibration above a predefined value. Used for earthquake detection and detecting physical contact with an external object. This function is deactivated when the robot is moving.

Motion Detection: A National Semiconductor visual motion detector is used to detect intrusion. This function is deactivated when the robot is moving.

Peripheral Vision: The center photocell in the vision array feeds a comparator configured to respond to a sudden change in relative light input.

Optical Vision: A three-photocell array operates in conjunction with two small strobed spotlights in head. Performs two functions:

1. With spotlights turned on, the robot can locate and track reflections from light-colored objects.
2. With spotlights turned off, the robot can locate and track the beacon on top of the battery-charging station.

Infrared Scanner: Will be mounted on top of head, assists in initial location and identification of charging station beacon.

Flooding: Spring-loaded sensor indicates presence of water on floor.

Hearing: Directional hearing for intrusion detection triggers alert condition and initializes a left or right scan in the direction of disturbance, for visual, infrared, or sonic confirmation.

Head Bearing (relative): Analog-to-digital conversion, represents position of head by a 4-bit binary number (approximately 10 degree resolution), allowing the processor to know the direction in which the head is pointing.

Battery Level: Monitors battery voltage. Initiates recharging search subroutine when level falls below an adjustable set point.

Sonar: Can operate in many modes. Used in collision avoidance, indicates presence of sonar reflecting object within three feet of front sensor, then supplies range to nearest obstruction on left and right for processor evaluation. This system currently consists of one National LM 1812 transceiver with three fixed mount transducers (the left and right transducers are not yet in place).

The sonar can be used for intrusion detection within a range of ten feet forward, left and right by recording the range to nearest echo, and then triggering an alert if any range changes (robot must be stationary in this mode).

Infrared Collision Avoidance: Four fixed transmitter/receiver units indicate reflections up to four feet (forward, rear, left, right). One additional unit will be later mounted on the head, and can be positioned at any angle up to 110 degrees either side of centerline, for object detection, locating open doors, etc.

Contact Sensors: 16 momentary-contact switches are placed at strategic points and activated by front, rear, and side bumpers upon contact with an obstacle.

Feelers: Six 8-inch spring feelers sense nearby objects for collision avoidance.

Bus Status Monitors: Numerous comparators monitor the voltage on various power distribution buses and initiate shutdown procedures in the event of a malfunction.

Head Position Status: A 1-bit signal indicates when the drive wheel position matches the processor position command.

Barometric Pressure: A pressure transducer supplies digital input to circuitry which triggers an alarm if barometric pressure falls sufficiently fast to indicate approaching storm.

Storm Monitor: Lightning discharges detected by AM radio are rectified and fed to a capacitor whose voltage level is monitored by a comparator that sounds an alarm if discharges become frequent enough to charge the capacitor beyond a preset voltage.

Charging Status: Signals the presence of 12 V on charging probe. Once the 12 V is detected, the forward winding of the tandem drive motors is disabled, bringing the robot to a halt.

Overload (drive): Comparator monitors the voltage across the drive power circuit breaker. If a high drive current is detected, the computer assumes a drive wheel is stalled.

Optical Intensity: The intensity of light striking the center photocell in the optical array is converted to a 4-bit binary number. This value is used in intrusion detection and beacon search subroutines.

RF Data Link: An 8-bit input port is controlled by a radio transmitter located at the main computer terminal up to 90 feet away. This function is used to provide external commands if desired, overriding whatever program was in execution at the time.

Drive Direction: Tandem reduction motors drive a single 4-inch drive wheel. Two forward and one reverse speeds are available. The drive torque is sufficient to surmount small obstacles even with additional payload.

Steering: Driven wheel (front) can be positioned in any one of sixteen different positions for a maximum of 80 degrees left or right of centerline.

Head Angle: The head can be positioned in one of sixteen positions when under computer control, or can scan continuously back and forth up to 110 degrees either side of centerline, stopping at any point within this range when under control of the automatic scan and track system.

Floodlight: An omni-directional floodlight can be turned on to illuminate a room. A 555 monostable multivibrator triggered by processor command turns on the floodlight for 30 seconds, or until room lights come on. (This is used as an assist for household members returning to a darkened house.)

Spotlight: 4-inch reflector designed for use when intrusion is suspected, etc. Controlled directly by processor, via data distributor interface board.

Ultrasonic Energy Beam: 3-inch transducer mounted atop the head just under the parabolic infrared detector emits extremely high level ultrasonic transmissions (sound pressure levels in excess of 120 dB). It has two modes:

1. At a fixed frequency of 50 KHz, this device appears intolerable to insects. This mode is activated by the processor when the robot is recharging. The ultrasonic noise seems to do a good job of eliminating fleas and roaches, while not affecting animals or human beings.
2. The second mode is used to evict an intruder. The amplifier section driving the transducer is fed a sine wave that sweeps repeatedly through the range of 5KHz to 25KHz. This signal is in the audible region for a portion of this range, with sufficient intensity throughout the range to cause extreme discomfort, disorientation, nervousness, and possibly nausea. It is very directional in nature, and causes no permanent damage. But imagine the effect on an unsuspecting would-be thief!

Speech: The 280-word vocabulary is created using National Semiconductor's speech synthesiser DT1050 Digitalker. Appropriate speech subroutines are called by the processor in response to input conditions.

Transmitter: Used to activate beacon on top of charge station when battery conditions require recharging (also energizes charger).

Ultrasonic Control Link: Used to activate a BSR wireless remote-control system for controlling appliances using standard power lines (can control up to sixteen lights and appliances). This allows processor control of home environment. (This system is not yet fully operational and will see several modifications before its final configuration.) This link will eventually allow telephone input to the robot over the radio data link to be used to turn home appliances on or off in any predetermined or calculated sequence.

Alarms: A Sonalert driven by 555 timer circuits produces distinctive beep patterns for various alarm conditions, such as earthquake, fire, low battery, etc., each distinguishable from the other, followed by voice description of event triggering alarms.

Seven-segment Display: National Semiconductor's clock and temperature module alternately indicates the time of day and room temperature when robot is in alert status.

Bar Graph: 10-segment LED bar graph gives visual indication of battery voltage. An analog meter which can be switched among the various power buses (12 V, 9 V, 5 V, etc.) is also provided.

System Overview

The systems in this robot receive power via various distribution buses originating from the power supply board mounted on the lower left side of the vertical column. (Left and right will normally be associated with the front view of the unit, corresponding to the observer's own reference.) These distribution buses are watched by the monitor board, and routed to the appropriate circuitry through three multi-circuit branches. The power supply board provides 12 V, 9 V, 7 V to 9 V, 5 V, and 3 V. Provision is made to power down certain distribution lines when the robot is not in alert status. These include power to the 7-segment clock display, the optical board, the strobe board, the head drive motor, and certain of the interface boards. The drive relay.board, which also furnishes power to the infrared driver board, is powered down by software. Certain bus lines are energized only when the system is in a passive mode; these include the seismic monitor and peripheral vision (light level change detection).

Of prime consideration is conservation of battery power. Much of the original circuitry has been redesigned to make use of CMOS components versus the original TTL, and, wherever possible, circuitry is de-energized when not needed.The SYM-1 consumes approximately 1.2 amps, and now must run continuously, but the 32K-byte Beta Expansion Board can be powered down when not needed, as can the externally mounted read-only memory.

Just above the SYM-1 on the front is the input/output enable panel, which has numerous switches and push buttons for enabling or disabling certain inputs or outputs, as required by test sequences or operating conditions.

Below that, and in front of the SYM-1, is Beta Computer Device's 32K-byte programmable memory expansion board, and just in front of this board is the Netronic's speech synthesis board which utilizes the National Semiconductor Digitalker chip.

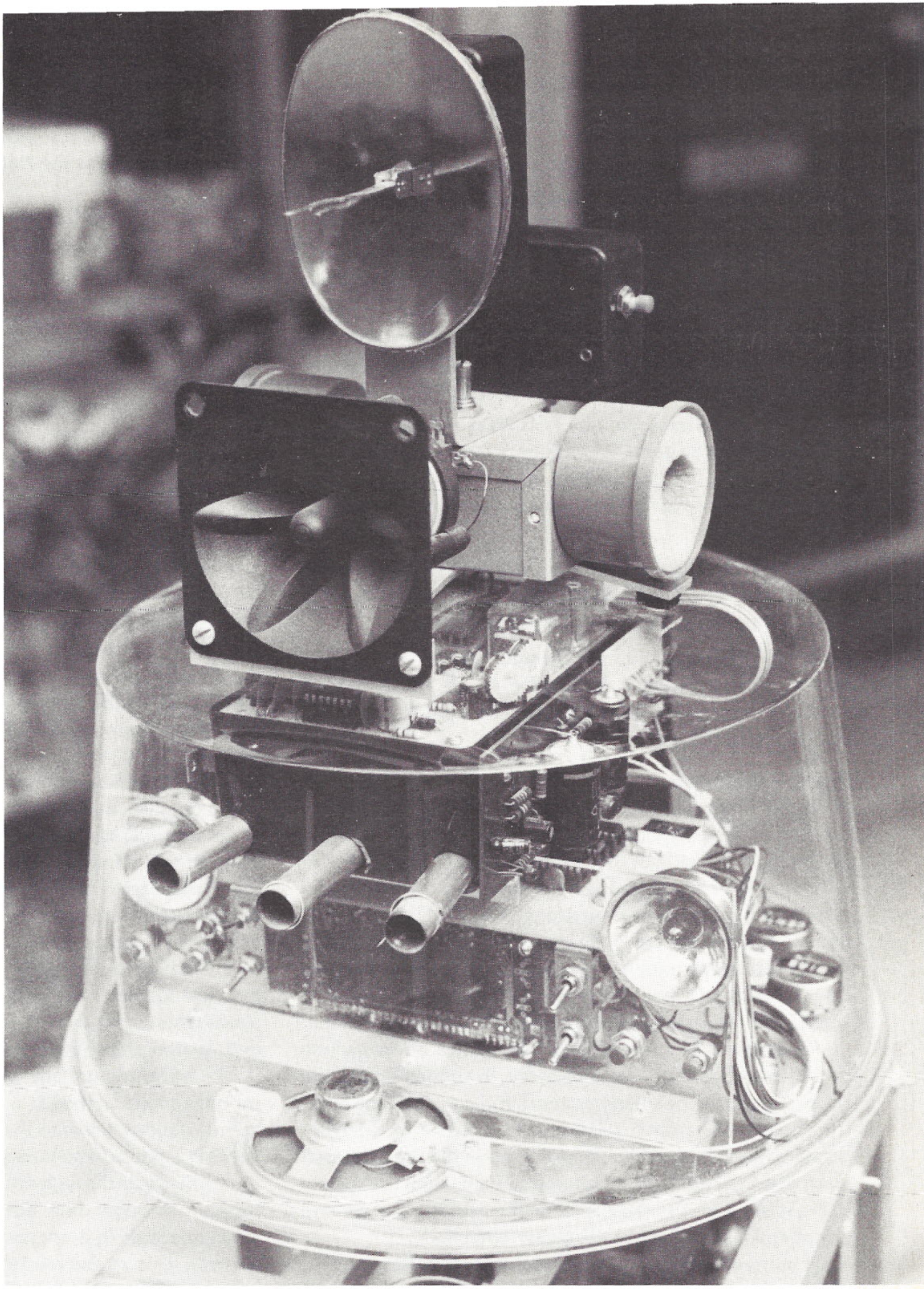
The drive wheel is powered by two 12 V actuators, mounted on either side of the wheel support cage. Each motor has a separate forward and reverse winding, with a common ground. An identical motor with a 2 ohm dropping resistor is used to position the drive wheel support cage (steering), and is coupled to a 10k ohm potentiometer which provides a 0 to 5 V analog signal to the analog-to-digital converter that supplies the interface circuitry with the steering angle expressed as a 4-bit binary number. A similar actuating motor is used to position the robot's plexiglass head, except that power is provided by a 7 to 9 V regulated supply, which allows the positioning speed to be adjusted to an optimum value for operation in conjunction with the fixed speed of the drive steering motor when the robot is in the tracking mode (i.e., homing in on the battery charger). The head motor and associated sensing potentiometer are mounted at the base of the robot, just forward of the battery, where there is more room, which helps keep the center of gravity low to the ground. The shaft extends up the center column, between the power supply board on the lower left and the sonar board on the lower right.

The monitor board is mounted on the power supply board, and it contains the circuitry for the battery level and power bus monitoring circuits, as well as the Sonalert driver circuits. The seismic monitor, which senses vibration, is enclosed in the plastic case that supports the monitor board, and its interface circuits are mounted on the monitor board, for convenience. The seismic monitor is reset by the robot going into an alert status, and triggering of the seismic monitor is wired to cause an alert. Since the robot is, by design, in an alert status when in motion, the seismic monitor is automatically deactivated unless the platform is immobile.

The various interface boards are mounted above the monitor board on the left side. These provide the necessary comunications between the processor and the real world it seeks to control. Also incorporated is expansion to an additional 32 inputs through data selectors, and an additional 32 outputs through data distributors. These are all driven simultaneously in a unique fashion by a common four-line address, which is also used to provide a head positioning command to the head controlling circuitry. (If I/O lines were scarce, it could also provide the steering command in a similar fashion, but since the SYM-1 is equipped with 71 I/O lines, and 64 more were added, the steering interface was given its own I/O port.)

The rear sensor panel holds the smoke detector, resurrected from an "as is" sale, the mechanical backup fire detector, the Sonalert, and the meter that monitors the various power distribution buses. Two banana plugs supply power to a logic probe when troubleshooting, and the temporary "evaluation" hookups, which the platform is designed to sup-

Photo 2: Closeup Of The Head Assembly. This illustration shows some of the details of sensors. The parabolic reflector will be used with an infrared detector to help locate the feeding station beacon. A black ultrasonic transducer and power amplifier is located below the reflector. Directly under the plexiglass cover is the strobe lamp board and its photocell array of 3 pickup tubes. Below this are boards containing circuitry for a clock/calendar integrated circuit and a thermometer sensor. Voice output is provided by a speaker.



port. On the lower right of the rear panel is located the AA Simulator Board. When the SYM-1 is disconnected from the actual sensors and connected to this board, commands can be fed to the interface boards in real-time for circuitry evaluation and troubleshooting. This is invaluable for stepping through a complicated sequence to eliminate bugs.

The sonar board is located on the right side of the robot, and is built around National Semiconductor's LM 1812 Sonar Transceiver. The circuitry provides a maximum range of about ten feet (twenty feet round trip). When operating in the collision avoidance mode this range is decreased through software to about two and a half feet by simply limiting the time spent waiting and watching for indication of an echo. This allows us to reduce range without having to alter transmission power. The sonar can also operate in a motion detection mode at full range when the platform is immobile, by simply calling up the Sonar Intrusion Detection subroutine.

The battery charging system is mounted in a small box midway up the charging tower. The homing beacon that allows the robot to locate the tower is at the top of the tower. At present this beacon consists of a 75 watt light bulb, positioned at the same height above the floor as the optical photocell array in the robot's head. Future plans call for the installation of a pulsed LED source to emit infrared light that would be detected by the parabolic infrared reflector mounted on top of the head. The charger's positive output is fed to an inverted pizza pan that serves as the base of the tower, and also the point of contact for the robot's charging pickup probe. The ground is connected to the metal pole that forms the beacon tower, and is electrically isolated from the pizza pan by a plexiglass insulator (see photo).

The charger pickup probe is mounted on a small box attached to the drive wheel support cage, and it is always positioned directly in front of the drive wheel. This probe routes the + 12 V from the charger through a diode on the monitor board to the battery via a fuse on the power supply board. The circuit is completed when the spring-loaded front bumper makes contact with the charging station pole. The processor then reads the "charging current present" input and stops the drive wheel. As a backup measure, a sensing relay in the charge probe circuit simultaneously disables the forward motor windings. In more than 200 observed dockings, this arrangement has only failed once — when a piece of rug lint snagged on the pickup probe. The lint insulated the probe from the pizza pan as the robot closed on the charging tower, and the processor interpreted the bumper contact with the pole as the striking of an obstacle because the front impact sensor triggered an interrupt and the probe status did not indicate contact with 12 V. The robot responded by backing up to the left, verifying a lock on to the beacon, and approaching from a slightly different angle, this time with success. The pickup probe was later modified by soldering a smooth contact to the probe end (previously a flexible spring).

The robot is brought into alignment with the charging tower through a complicated but reliable process that consists of locating the light source, verifying that it is the beacon on the charger, tracking it with head angle while turning towards it, and then running into the charger tower to make an electrical contact. (The verification step was added as an afterthought: in an earlier case the automatic scan and track circuit accidentally locked on to a table lamp situated at the same height as the optical photocell array in the head which caused the robot to attempt docking with the lamp.)

When the battery condition goes below the set point for more than five seconds, the flip-flop on the monitor board changes state and the processor initiates the recharging search subroutine. The transmitter is activated, which turns on the battery charger and homing beacon at the charging station. The processor also enables the automatic scan and track circuit on the optical board. The head begins to scan left and right, seeking a point source of light of sufficient intensity to trigger the center photocell comparator. This scan action is controlled by the scan flip-flop on the optical board in the robot's head. The scan flip-flop is reset and set by limit switches at both extremities of head travel, causing the motor to reverse direction and the head to scan the other way. This action continues as long as no light source is detected. If any of the three optical comparators goes high, indicating a light has been found, the scan flip-flop is deactivated and the tracking inputs take over control of the head positioning motor.

The tracking inputs come from the left and right photocells in the array. Their respective comparator outputs indicate a greater intensity either side of center, in reference to the center photocell output. The appropriate drive winding is energized, and the head turns to regain maximum intensity at the center photocell, thus tracking the source. (If by chance both left and right photocells showed intensities greater than center, the head remains motionless.) When the array outputs indicate the head is correctly positioned (i.e., pointing at the source), the head positioning motor will be de-energized.

Once the processor ascertains that the head has located the beacon, it interrogates the source to verify that it is indeed the beacon. Verification is accomplished by turning off the transmitter and watching to see if the beacon also goes out. If the source is not the beacon, the scan is reinitiated and the process repeats.

Assuming the source is the beacon, the processor reads the head position and sends a command to the steering motor to position the drive wheel at the same angle. As the platform turns, the head automatically tracks the source, and the bearing to the beacon decreases. The processor subsequently decreases the turn angle until eventually the source is directly in front of the platform.

The task of docking with the recharger is greatly simplified by the design of the charging tower, as well as the pick-up probe. The charging tower can be approached from any direction. The geometry is such that as long as the front bumper contacts the upright pole, the probe will be touching the pizza pan underneath. Because the front bumper is 12 inches wide, there is a very reasonable margin for alignment error, so even if the robot is traveling so as to miss contact with the tower by, say, one inch, a last-minute correction command from the processor (at a point as late as six inches from contact) would still allow plenty of time for a perfect docking. (At that close range, the head would be indicating a 45 degree bearing to the beacon, instead of the desired zero degrees. A subsequent 45 degree turn in the desired direction would result in contact close to the center of the front bumper.)

The optical photocell array can also operate in a second mode, in conjunction with the two small spotlights mounted on either side of the clock display in the head. In this mode, the automatic scan and track circuit seeks out and tracks reflections from light-colored objects. While scanning, the spots are strobed by the strobe board mounted on top of the box that supports the three photocell tubes in the head. This conserves power; the processor turns the spotlights on continuously as long as there is a reflection. The spotlights produce identical areas of high illumination on either side of the center reference photocell. These are detected by the left and right photocells on reflective surfaces, up to a range of about five feet. Beyond this point, the beams converge and there is no relative brightness with respect to the center photocell, so objects beyond five feet are ignored. This system is extremely limited in that only light-colored objects can be detected, and it can be swamped by ambient light. (It was incorporated because it provided justification for the flashing eyes, which all robots are expected to have.) It does, however, produce some interesting responses if a passerby in a light-colored shirt arouses the robot's attention.

Conclusion

The design and construction of a robot is a continuous project, for whenever one system is perfected, another problem or another approach to a problem arises. It's a project that will teach anyone about hardware and software solutions.