

RANGING SENSORS FOR OBTAINING VISION INFORMATION: SUCCESSSES AND SHORTCOMINGS

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ABSTRACT

This paper describes an investigation of the feasibility of using low-cost, off-the-self ranging sensors for obtaining vision information. A polaroid ultrasonic ranging system was obtained and the sensor was mounted so that its direction could be controlled by an IBM XT PC-compatible. Then an interface board was designed and software was written to allow communication between the sensor, the positioning system and the computer. In addition, software was written to gather distance and angle measurements, and to analyze the data obtained. This ranging system worked well for obtaining distances to objects, however, its resolution for measuring angles was not as good. Thus, it was concluded that the system described would be applicable where details about an object's shape are known or not important, and the distances to the objects are of prime importance.

KEYWORDS: ultrasonic ranging, vision, robotics

INTRODUCTION

To realize the full potential of a robot system, one must have an effective vision system. In fact, it can often be concluded that vision systems are bottlenecks in effective robot system. Features of elaborate vision systems are high cost and physical encumbrances. With these observations as motivation, a project was initiated to investigate the feasibility of using low-cost, off-the-shelf ranging sensors for obtaining vision information.

A Polaroid ultrasonic ranging system was obtained, a positioning system was developed, and an IBM XT PC-compatible was made available. An interface board was designed to enable the ultrasonic ranging system and the positioning system to communicate with the PC. These constituted the main components of the hardware.

Next, software was written to position the sensor, gather distance measurements, and analyze the data in order to obtain information about objects of interest.

Overall, the ultrasonic ranging unit worked very well for obtaining distances to objects. It did not work as well when attempting to obtain detailed shapes of objects because the ultrasonic beam is not sharp enough to obtain high resolution of angular positions. Thus, the sensor could be useful where high angular position resolution is not

required. This could include applications where details about an object's shape are already known and distances to it are of prime importance, or where the application is such that detailed shape information is not critical.

HARDWARE DESCRIPTION

The heart of the hardware is the Polaroid Ultrasonic Ranging System. This system is comprised of an electrostatic transducer similar to that used in the Polaroid SX-70 camera, the ultrasonic transceiver board, and the Experimental Demonstration Board (EDB). The first three components combine to form a sonar system capable of detecting the presence and distance of objects within a 0.27 m (0.9 ft) to 10.7 m (35 ft) range.

The electrostatic transducer acts as both a speaker (in the transmit mode) and a microphone (in the receive mode). In operation, a burst of 56 pulses (transmitted at 49.1 kHz) is emitted toward the target and the resulting echo is detected. The total distance travelled can then be calculated by multiplying the elapsed time between transmission and detection by the speed of sound.

The ultrasonic transceiver board controls the operating mode (transmit/receive) of the transducer. It is comprised of three sections: the digital section, the power interface section, and the analog section. The digital section generates the burst of ultrasonic pulses transmitted by the transducer and the power interface section initiates the transmission of the pulses from the transducer. When the return echo from the target is received by the transducer, it is amplified by the analog section. This amplified signal is finally sent to the digital section to produce the echo received signal.

The Experimental Demonstration Board (EDB) contains the circuitry required to convert the transmit/receive time interval into a distance value and display it on a three digit LED display.

The sensor positioning system is comprised of the sensor set into a pointer fixture and mounted atop a stepper motor. In order to determine the angular position of the sensor at any moment in time, a protractor was fastened onto a small platform. The shaft of the stepper motor was inserted through the platform and the sensor/pointer fixture was attached to the protruding shaft. The angular position of the sensor can be determined by observing the position of the pointer on the protractor. This provides one dimensional information only, but it could be extended to two dimensions

by varying the angle of the sensor about the horizontal axis parallel to the face of the sensor.

An interface board was designed which enables the computer to communicate with the ultrasonic ranging system and the sensor positioning system.

The ultrasonic ranging system interface circuit consists of four CMOS devices: a 4 x 1 MUX (DC4052), a monostable multivibrator (CD4528), a 4-bit latch (CD4042), and an output buffer (CD4050). The interface circuit is shown in Fig. 1. This circuit decodes the three distance digits on the EDB and latches the digits so that the PC can read them.

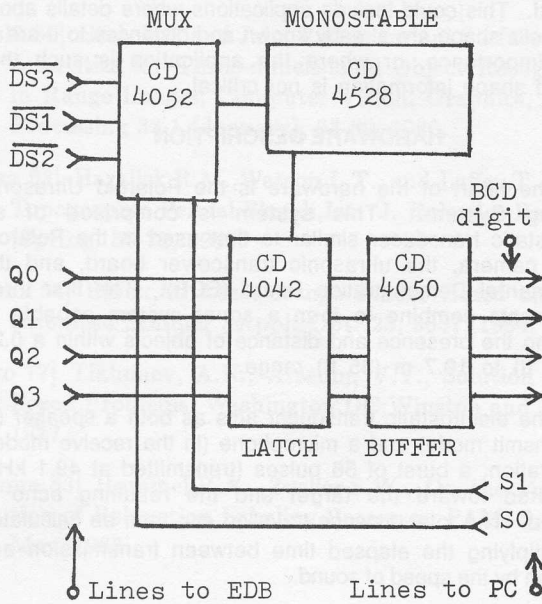


Fig. 1 Interface between ultrasonic ranging system and PC.

When a valid digit is present at Q0 through Q3, the appropriate digit select line (DS) will be low. For example, when the least significant digit (LSD) appears on Q0-Q3, the DS1 line will be low. Similarly, when the most significant digit (MSD) is valid on Q0-Q3, the DS3 line will be low.

The digit select lines are connected to the inputs of the MUX. A 2-bit parallel select code from the PC determines which of these digit select lines will pass through to the MUX output. For instance, to select the LSD, the select code would be 00. Each valid select code and its corresponding digit select line is shown in Table 1.

The computer selects a digit by outputting a select code to the MUX. After the selected digit becomes valid, its digit select line (DS) will go low, pass through the MUX to the output (Y), and trigger the monostable. The resultant

TABLE 1 Select Codes

| Select Code | | Digital Select Line |
|-------------|----|---------------------|
| S1 | S2 | |
| 0 | 0 | DS1 (LSD) |
| 0 | 1 | DS2 |
| 1 | 0 | DS3 (MSD) |
| 1 | 1 | not used |

monostable output pulse will latch the digit (which will be present on Q0-Q3) at the output of the 4-bit latch device (see Fig. 2). The digit will now be available as a 4-bit BCD value for the computer. The buffer is required to convert the CMOS voltage levels of the EDB and interface circuit to the TTL levels of the computer.

The sensor positioning system interface circuit consists of only one device: an MC1413 Darlington Transistor Array

The stepper motor is moved 7.5 degrees per step by energizing each of its inductors one at a time in succession. A 4-bit value of either 0001, 0010, 0100, or 1000 output from the computer will do exactly this. The Darlington transistors are required to drive the stepper motor and to buffer the computer from the stepper motor. They were chosen for their high breakdown voltage and internal suppression diodes which ensure freedom from problems associated with inductive loads.

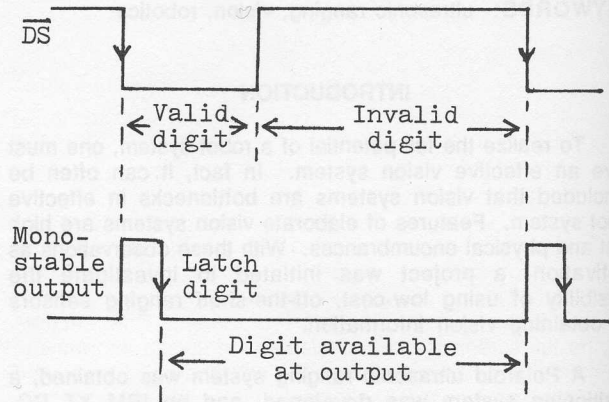


Fig. 2 Valid digit timing diagram.

SOFTWARE DESCRIPTION

The software for the system was written entirely in Turbo Pascal on an IBM-XT compatible PC. It is responsible for positioning the sensor, obtaining the distance measurements from the sensor, processing these measurements in order to locate objects within the sensor's "field of view", and displaying the results on the computer terminal screen.

An operational flowchart of the system is shown in Fig. 3. As can be seen, the software is extremely modular with each module responsible for only one task. This results in a program which is easy to comprehend, maintain, and debug.

The program requires a minimal amount of input from the user. First, the user must specify the maximum object distance which is of interest. This can be any value within the operating range of the sensor (0.27 m to 10.7 m). This feature enables the user to disregard any objects beyond a certain distance.

A "field of view" for the sensor is accomplished by moving the sensor through different angular positions. This is called a "sweep". The program allows the user to specify a starting and an ending angular position for the sweep. The maximum sensor sweep is 180 degrees (from -90 degrees to +90 degrees) and the minimum sensor sweep is 7.5 degrees. The minimum sensor sweep is limited only by the step size of the stepper motor.

PROGRAM EXPLANATION

After the system variables (such as maximum object distance, sensor starting and ending angular positions, sensor positioning value, and sensor direction) are initialized, the object distance is read by the computer via the ultrasonic range system interface as described earlier.

A dynamic data structure known as a "linked list" is used to store the sensor position and corresponding distance that was measured at that position. A linked list was chosen to store this information because of its flexibility. The number of distance measurements obtained can vary each time the program is executed. With a static data structure (such as an array), a fixed size must be determined prior to compilation. This fixed size will effectively set a limit on the number of distance samples which can be obtained during a sweep. The size of a linked list is dynamic (ie. it is not fixed). It may change during program execution. Therefore, the use of a linked list as a primary data structure affords the program a versatility which could not be realized had a static array been chosen.

The polar coordinate of the sampled point (ie. the sensor angle (q) and the measured distance (r)) is converted into X-Y coordinates and plotted on the terminal screen. There is an automatic scaling procedure which scales each point such that the maximum object distance of interest to the user is the farthest point on the screen. This ensures that the full screen is used to display the sweep information. The current angular position and the distance being measured at this position are constantly displayed on the screen as an aid to the user.

If the sensor has not yet reached one of the user supplied starting or ending angular positions once the sampled point is displayed on the screen, the sensor is moved to the next angular position and the aforementioned system variables are updated in anticipation of the next point to be sampled.

If, after the sampled point is displayed on the screen, the sensor has reached a starting or ending angular position limit, the list of sampled points is processed and any identified objects are displayed on the screen. The above process is repeated with the sensor now travelling in the opposite direction.

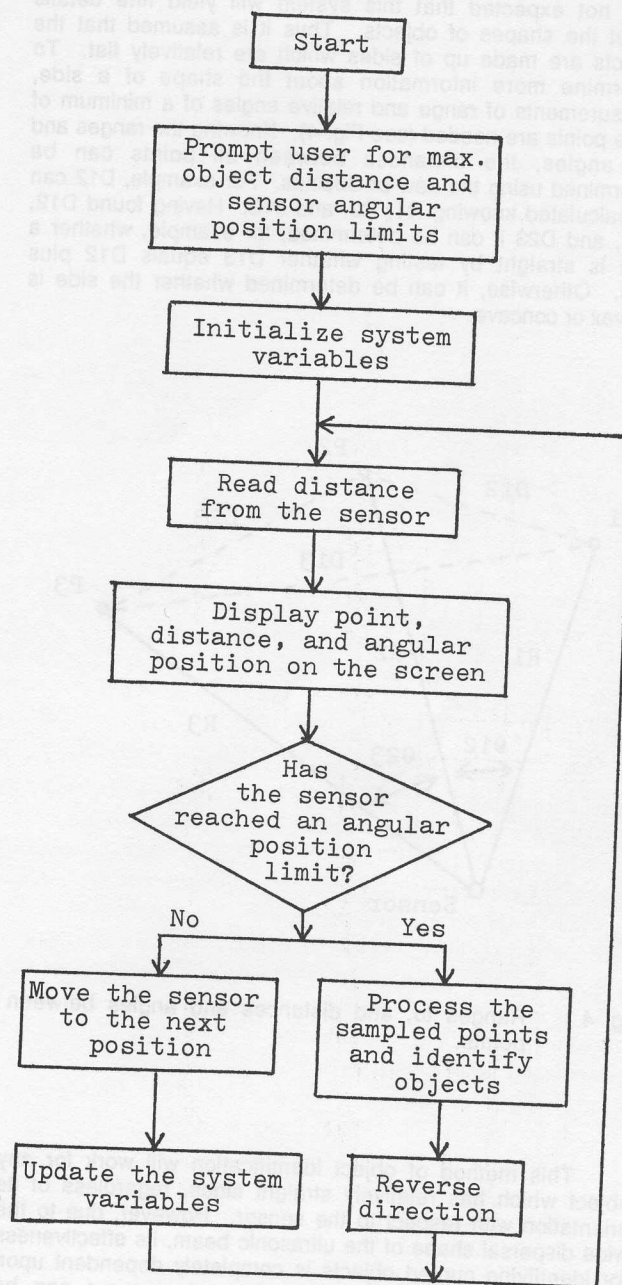


Fig. 3 Operational flowchart of system.

THEORY BEHIND OBJECT IDENTIFICATION

Since the ultrasonic beam emitted by the sensor is not sharp enough to obtain high resolution of angular positions, it is not expected that this system will yield fine details about the shapes of objects. Thus it is assumed that the objects are made up of sides which are relatively flat. To determine more information about the shape of a side, measurements of range and relative angles of a minimum of three points are needed (see Fig. 4). Knowing the ranges and the angles, the distances between all points can be determined using the Law of Cosines. For example, D_{12} can be calculated knowing R_1 , R_2 , and θ_{12} . Having found D_{12} , D_{13} , and D_{23} it can be determined, for example, whether a side is straight by testing whether D_{13} equals D_{12} plus D_{23} . Otherwise, it can be determined whether the side is convex or concave.

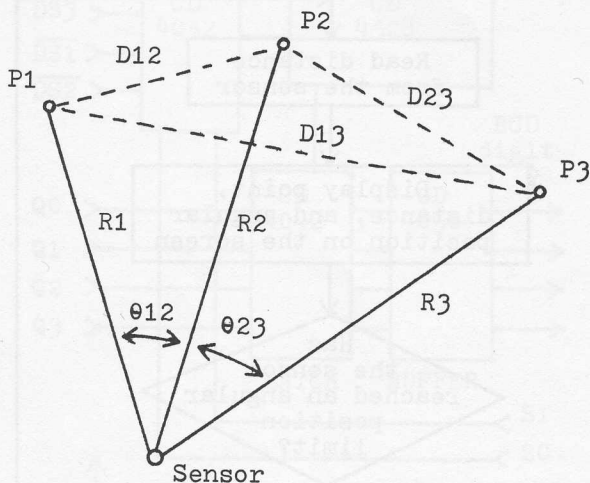


Fig. 4 Ranges to, and distances and angles between points.

This method of object identification will work for any object which has relatively straight sides, regardless of its orientation with respect to the sensor. However, due to the wide dispersal shape of the ultrasonic beam, its effectiveness for identifying curved objects is completely dependent upon the severity of the curvature. A gradual curve can be identified properly easier than a harsh curve.

RESULTS

The object identification system was tested in two phases. The first phase consisted of testing only the object identification algorithm. The second phase involved the testing of the algorithm and the sensor together.

In order to effectively test the accuracy of the object identification algorithm, any error introduced by the sensor would have to be suppressed. For this reason, the sensor was not used to gather distance data during the initial tests.

Instead, different object configurations were sketched to scale with each succeeding object more complex than the previous one. All of the distances were measured manually and entered into the computer.

The results obtained by the algorithm for each trial were exactly as expected. Therefore, these tests showed that the algorithm was capable of accurately detecting, defining, and displaying an object.

Once the integrity of the algorithm was established, Phase Two of the testing was begun. Objects were simulated using various pieces of cardboard. During these tests, all of the range measurements were obtained directly from the sensor and the shapes of the pieces of card were displayed by the algorithm. A typical result is shown in Fig. 5.

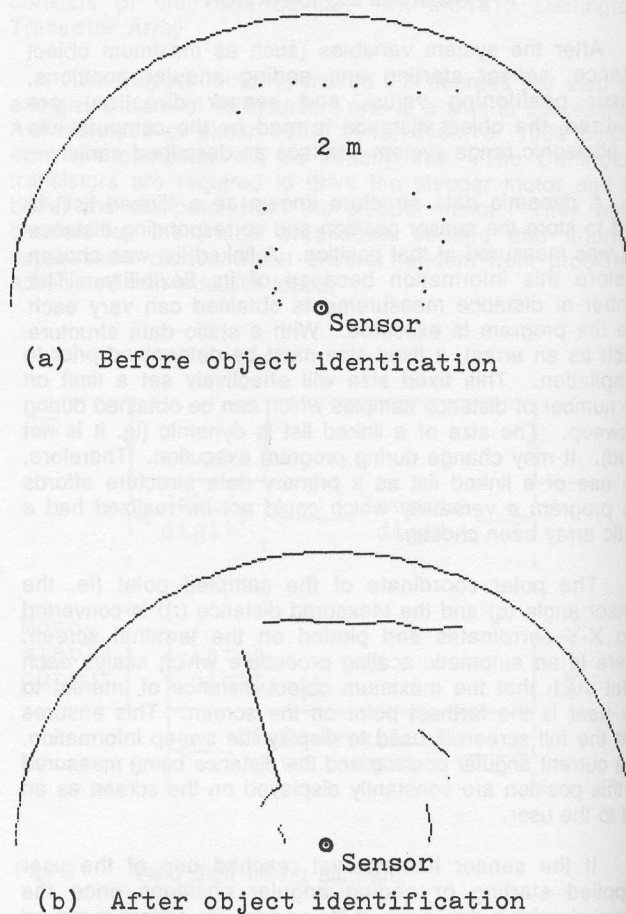


Fig. 5 Typical results of identifying objects using ultrasonic sensor and object identification algorithm (the semicircle represents the maximum distance of interest).

The results were found to be quite good considering the accuracy of the ultrasonic beam. For instance, the signal strength of the returned echo depends upon the surface structure of the object. Usually, only limited parts of an object will reflect much of the echo back to the sensor. This condition was observed when the signal from the sensor struck an object at an oblique angle. In some cases, an echo was never returned to the sensor, but instead bounced off into space. However, considering the low cost of the sensor unit, it performed admirably.

The beamwidth of the signal is very important in robotics applications. It is important that the signal not spread out too much so that the system detect unwanted objects to the side, and that the beam is not too narrow to miss objects of interest.

An attempt was made to narrow the beamwidth by attaching horns of different shapes to the front of the sensor. The horns did sharpen the beam to some extent, but not enough to have a significant effect on the data.

CONCLUSIONS

The object identification system worked well for detecting objects. The algorithm which was developed proved capable of detecting, defining, and displaying various objects. This was done with the sensor rotated about a single axis, thus, it provided two dimensional information about the object. To get all three dimensions the sensor would, in addition, have to be rotated about a horizontal axis parallel to its face.

The ultrasonic sensor provided a low-cost means of obtaining distances to objects. However, it was discovered that the ultrasonic beam was not sharp enough to obtain fine details about shapes of objects. An attempt was made to narrow the shape of the beam, thereby increasing the resolution of the system. Although the beam was sharpened somewhat, it did not produce any profound effect on the data.

Therefore, this system could be useful where high resolution is not important. This could include situations in which the shape of an object is already known or not of interest.