Building a Ring of Ultrasonic and Infrared Sensors For a Mobile Robot

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***Abstract*—This paper describes the construction of a ring of 16 ultrasonic and infrared sensors as an important part of a mobile robot. Considering that commercial ultrasonic controller boards only drives one sonar, we describe a design to use only one controller board and 16 ultrasonic transducers. Both ultrasonic sensors and infrared sensors are under control of a 68HCS12 microcontroller and the mobile robot accepts commands using an standard RS232 serial connection.**

I. Introduction

Nowadays mobile robots are in research laboratories as well as in industry, hospitals, museums, and an important issue is to have a powerful and reliable mobile robot.

Unfortunately most Mobile Robotic research in Mexico is done using imported mobile robots. However, these robots have several disadvantages: 1) they are expensive, 2) maintenance is slow and expensive, and 3) normally they are closed systems, without flexibility to add new capabilities.

To overcome this disadvantages, we develop an open, flexible, reliable, powerful and expandable differential mobile robot, designed and built locally. It is based on the Linux operating system and commercial hardware for sensors and actuators. All the software required by the robot was already part of Linux, or it was developed using tools under the GNU General Public License. In other words, there is no proprietary code.

A previous paper [1] describe details of the hardware and software of the brushless motor controller of the mobile robot. The mobile robot uses two brushless motors to driver the two wheels of the mobile robot.

Now this paper presents details of a ring of the ultrasonic and infrared sensors designed and build as a part of our mobile robot. These sensors increase the functionality of the mobile robots to detect obstacles close to the mobile robot, even transparent obstacles.

The rest of this paper is organized as follows. Section II presents the ring of ultrasonic sensors (or sonars) using only a single sonar controller board and 16 ultrasonic transducers. It includes a description of the operation of the ultrasonic sensor. Section III presents the ring of infrared sensors and the principle of operation of them. Section IV shows some details of the microcontroller used to control both types of sensors. Finally, some conclusions are given in Section V.

II. Ring of 16 ultrasonic sensors

Figure 1 shows the principle of operation of ultrasonic sensors, or sonars. In a first step, the ultrasonic transducer emits a high frequency sound and then; in a second step, the sensor waits for an echo and the same transducer now functions like a microphone to hear echoes. The distance to the nearest object can be computed from the elapsed time between the sound emission and the reception of the first echo.

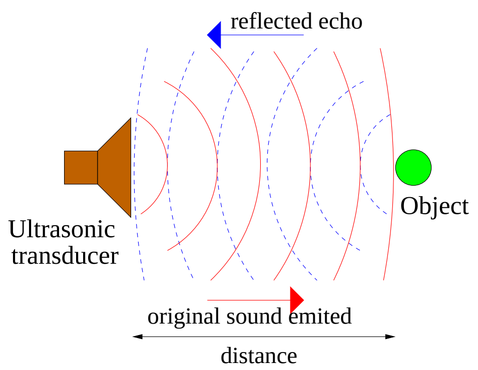

Fig. 1. Ultrasonic sensor operation

A. The Ring of Ultrasonic Sensors

The sonar ring (see Figure 2) is a custom-made ring of 16 SensComp/Polaroid Environmental Grade Transducer and a 6500 Series Sonar Ranging Module [1]. Polaroid sonar transducers have an effective measuring range from about 4 inches to 30 feet, over a field of view of approximately 15 degrees.

The 16 transducers are operated by one Polaroid 6500 driver via a 74LS154 4-line to 16-line demultiplexer chip, as illustrated in Figure 3. The driver board is connected to the microcontroller, which issues a trigger signal (init) to tell the driver board to send out a sonar *ping*. The microcontroller then *listen* for the echo of the ping on the sonar driver

[1]Available in http://www.acroname.com/robotics/parts/R135-SONAR4.html

Fig. 2. Ultrasonic and infrared sensors. Ultrasonic transducers are rounded and infrared sensors are black

board's output (echo). The demultiplexer is located between the driver board and the transducer; before each ping, the microcontroller selects which transducer should be connected for the ping. This is done, because the demultiplexer takes four address lines from the microcontroller and selects one of the transducers. The signal that the 6500 driver board uses to send out a ping on the sonar transducers is approximately 400 volts peak-to-peak. Therefore, commonly available logic-level multiplexer chips can not be used to switch this signal to the right selected transducer. Besides that, the device must be able to drive the few milivolts generated by the transducer when it receives an echo. To overcome this problem, we follow the solution presented in a draft report [2] by D. J. Musliner and R. A. Larsen.

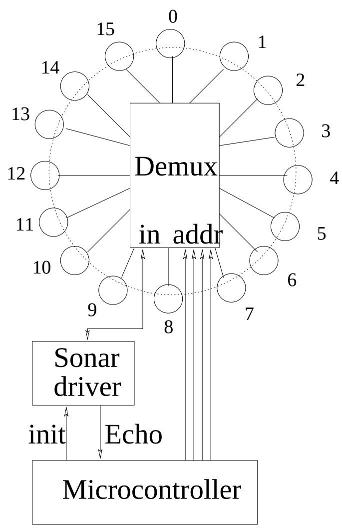

Fig. 3. Sonar controller

Figure 4 shows the schematic circuit of the sonar controller we built. The Optically Coupled Bilateral Switch Light Activated Zero Voltage Crossing Triac MOC3042 (see the DigiKey catalog, Isocom MOC3042 [2]) is used to connect the sonar driver board to the desired ultrasonic transducer (using $EN1$ and $EN2$ terminals on the Polaroid 6500 board), under control of the demultiplexer output. The desired MOC3042, and hence the desired transducer, is activated when the associated output of the multiplexer (Y0 to Y15) takes a low level (0

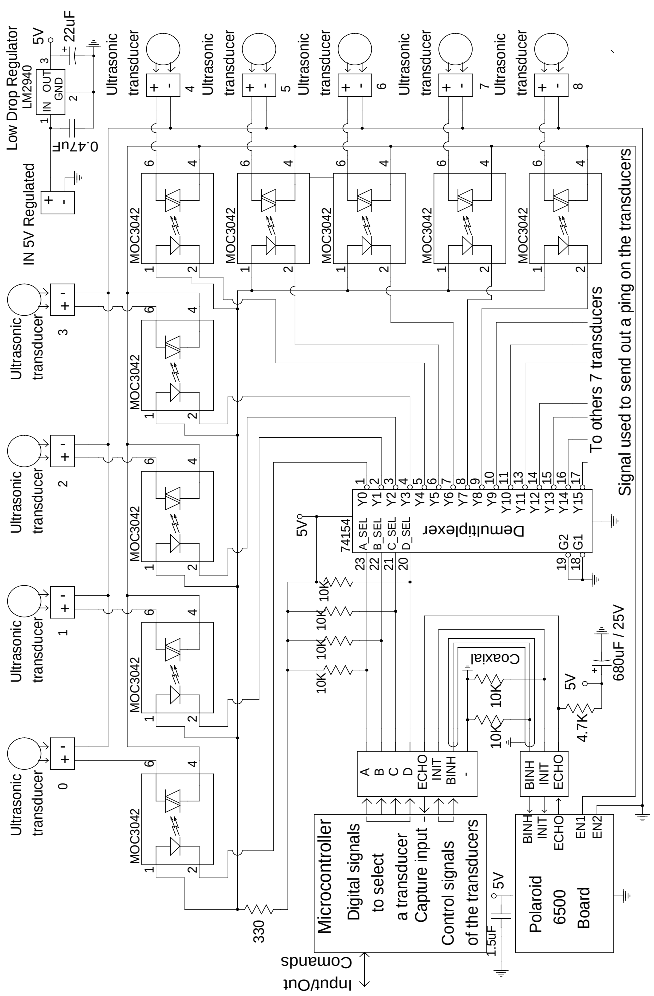

Fig. 4. Sonar controller circuit.

volts). Digital output lines A, B, C, and D gives the digital representation of the selected ultrasonic transducer, from 0 to 15.

Following the MOC3042 recommendations, a 330Ω resistor, between 5V and pin 1, is used to allow a 10mA current.

It is important to note that a coaxial cable is used to connect the $BINH$ signal from the microcontroller to the Polaroid 6500 board, since this signal is extremely sensitive to electromagnetic noise.

According to the specifications of the ranging board, a 4.7kΩ resistor must be used to pull the ECHO line high. When the sonar pulse occurs, the ranging board draws 2 amperes of current for a fraction of a millisecond. Such a large current can be a challenge for the robot's power supply; we get good results installing a capacitor of 680μF from power to ground near the ranging board. Also, we connect a ceramic capacitor of 1μF directly to the backside of the ranging module between the V_+ and GND pins. The ranging board is a sensitive, high-gain device and without this second capacitor, the electric

[2] http://www.cs.umd.edu/users/musliner/sonar/tr.ps

noise on the V_+ line can cause the Echo line to go high as soon as the sonar pulse terminates.

B. *Sonars operation*

The 6500 Series is an economical sonar ranging module that can drive all SensComp/Polaroid electrostatic transducers and operates over s supply range of 4.5 to 6.8 volts. This module, with a simple interface, is able to measure distances from 6 inches to 35 feet. The typical absolute accuracy is $\pm 1\%$ of the reading over the entire range. The sonar transmit output is 16 cycles at a frequency of 49.4 kilohertz.

There are two basic modes of operation for the 6500 Sonar ranging module: single-echo mode and multiple-echo mode. When INIT is taken high, drive to the Transducer output occurs. Sixteen pulses at 49.4 kilohertz with 400-volt amplitude will excite the transducer as transmission occurs. At the end of the 16 transmit pulses, a dc bias of 200 volts will remain on the transducer as recommended for optimum operation. In order to eliminate ringing of the transducer from being detected as a return signal, the Receive input of the ranging control IC Is inhibited by internal blanking for 2.38 milliseconds after the initiate signal. If a reduced blanking time is desired, then the BINH input can be taken high to end the blanking of the Receive input anytime prior to internal blanking. This may be desirable to detect objects closer than 1.33 feet corresponding to 2.38 milliseconds and may be done if transducer damping is sufficient so that ringing is not detected as a return signal. In the single-echo mode of operation (5), all that must be done next is to wait for the return of the transmitted signal, traveling at approximately 0.9 milliseconds per foot out and back. The returning signal is amplified and appears as a high-logic-level echo output. The time between INIT going high and the Echo (ECHO) output going high is proportional to the distance of the target from the transducer. If desired, the cycle can now be repeated by returning INIT to a low logic level and then taking it high when the next transmission is desired.

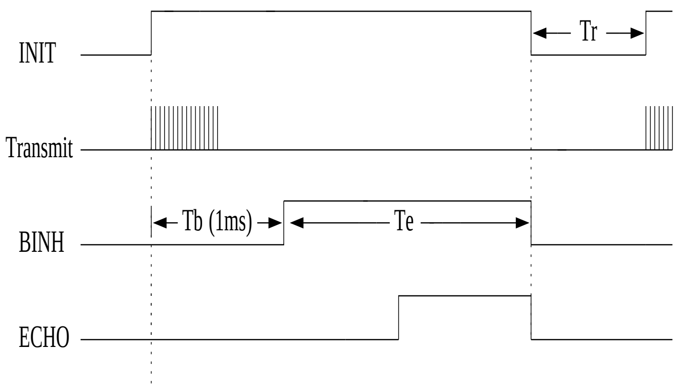

Fig. 5. Sonar operation

The task of measuring the time between INIT and ECHO is actually performed using a specialized circuit in the 68hc12

TABLE I

COMMANDS TO CONTROL THE SONAR RING

Command	Parameters	Function
S	$d0\ d1 \cdots d15$	Define the firing sequence of the sonars
s0		Turn off the sonar ring
s1		Start firing sonars
s2	te	Set firing parameters
s		Return sonar readings

microcontroller's timing system. The timing system has a free-running 16-bit counter that simply counts up form power-on, incrementing its count once every clock tick (the actual rate depends on the timer used to drive the 68hc12 and the setting of several scaling bits). The *input capture* circuit allows us to capture the value of that timer a particular input of the microcontroller is raised from low to high. Thus the ECHO line of each 6500 driver board is tied to one of the 68hc12's input capture circuits. When the driver software sends out the INIT signal, it stores the value of the timer into a memory location. After the fixed delay Te, the driver software checks to see whether the input capture circuit has been triggered (indicating that an echo was detected during that time delay) and, if so, it subtracts the stored INIT time from the captured (ECHO) timer value, thus giving a high-resolution measure of the sonar signal's travel time. A simple linear scaling factor transforms this value into the measured distance in centimeters.

The communication between microcontroller and the notebook computer is done using standard serial connections. In order to have a human readable interface, commands and robot answers are sent using plain text over the serial connection. Table I shows the commands related to the sonar ring.

III. Infrared Sensors

The robot has a ring of 16 GP2D02 Infrared sensors from Sharp [3] to measure distances from obstacles. The GP2D02 consists of an emitter and a position sensitive detector. The GP2D02 computes the distance to an object, based on triangulation. The basic idea is this: a pulse of IR light is emitted by the emitter (see Figure 6). This light travels out in the field of view and either hits an object or just keeps on going. If the light reflects off an object, it returns to the detector and creates a triangle between the point of reflection, the emitter, and the detector. The angles in this triangle depends on the distance to the object. The detector can then determine what angle the reflected light came back at, and therefore, it can calculate the distance to the object [3]. The GP2D02 measures distances in the range 10cm-80cm and return range as an eight bit value. Since the GP2D02 has only one output pin (V_{out}) and one input pin (V_{in}), we active a clock in the input pin (using the microcontroller) to get the output data.

Figure 7 shows the V_{in} signal that sends the microcontroller to the sensor, in order to get a range reading. It is started with the V_{in} high then hold it low for 70ms or longer. The sensor makes its measurement during this period. Then the

[3] http://www.active-robots.com/products/sensors/sharp/gp2d02.pdf

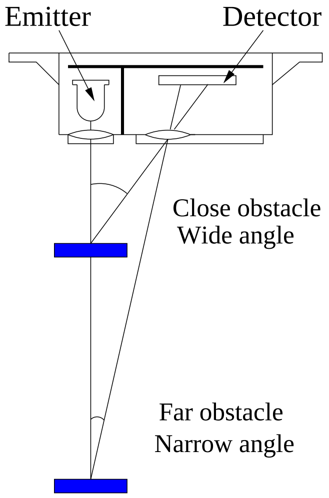

Fig. 6. Infrared sensor GP2D02

microcontroller sends 8 pulses as shown in the figure. Wh
V_{in} goes from high to low, the microcontroller reads V_{ou}
The most significant bit of the range measurement comes fir
Higher numbers in the result correspond to shorter ranges [4

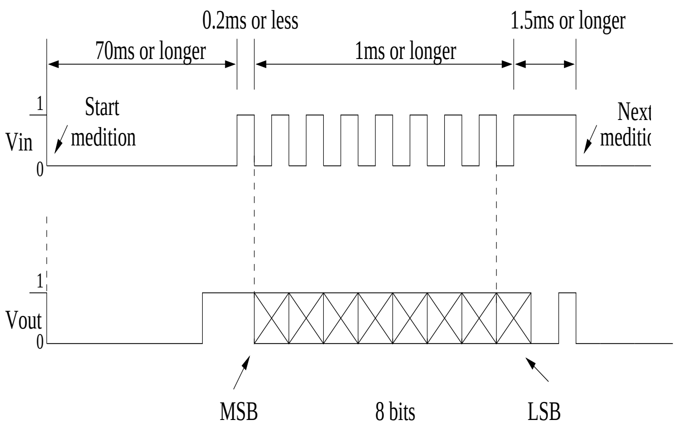

Fig. 7. Infrared sensor operation

Figure 8 show the output of the GP2D02 sensor versus the distance to an object, given by the manufacturer; while Figure 9 shows, as points, the actual data from a GP2D02 sensor. Experimentally we found the following expression (shown in Figure 9) to compute easily the distance L in cm, given the sensor reading (DEC):

$$L = \frac{2277.43}{DEC - 46.168} - 5.877 \quad (1)$$

A. Infrared Sensors Controller

Figure 10 shows the circuit of the infrared sensor controller. We take a distance reading for all 16 Infrared sensors at once. To read the output byte the 16 Infrared sensors we use 16 input signals of the microcontroller (Port A and Port B). But to activate the 16 Infrared sensors we use only 4 output signals

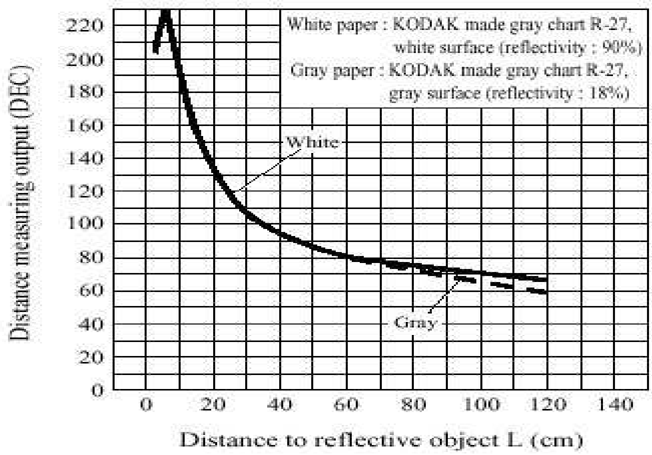

Fig. 8. GP2D02 Infrared sensor

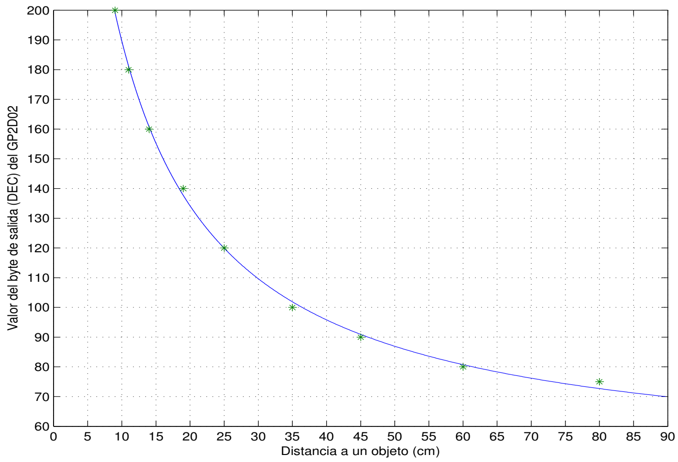

Fig. 9. Testing a GP2D02 sensor

of the microcontroller (A, B, C, D). This is possible because the input pin of 4 sensors share the same output signal of the micro controller. For example, the input A is shared for sensors 1,4,8,12.

IV. MICROCONTROLLER

We use the Adapt9S12DP256 card [4], a compact, modular implementation of the Freescale 9S12DP256C microcontroller chip. It can run up to 24Mhz and two 50-pin connectors bring out all I/O pins of the microcontroler. It includes all necessary support circuitry for the microcontroller, as well as a 5-Volt regulator and two RS232 transceiver on-board.

The program for the microcontroller was developed in the C language using a public domain compiler [5] for the HCS12 microcontroller, available in Linux.

V. CONCLUSIONS

We have briefly described a ring of 16 sonars and infrared sensors suitable for a mobile robot. Individual pings of sonars

[4]http://www.technologicalarts.ca
[5]http://www.gnu.org/software/m68hc11/m68hc11_gcc.html

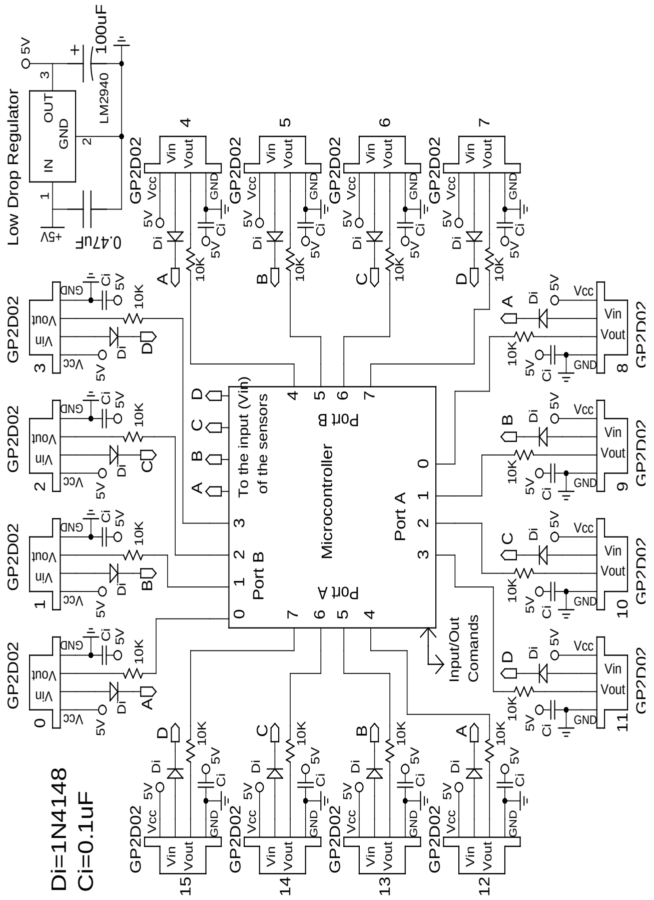

Fig. 10. Infrared Sensors Controller.

or infrared sensor works as expected but additional tests, considering the whole rings of sensors, are going to be performed.

In a previous paper [1] we have described another part of the mobile robot, the brushless motor controller that moves the mobile robot. We hope this information would be useful to other researchers or small companies interested in building mobile robots, as a good alternative to buy imported mobile robots. In the near future we are going to help Cervantes Co., a small company in Paracho Mich., Mexico to build and sell Mexican Mobile Robots with sonar and infrared sensors. This company sold a mobile robot (without ultrasonic and infrared sensors) to the UNAM in 2006, and with this robot the UNAM won the third place in the robot@home 2007 international competition in Atlanta, USA.

References

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[2] *MOC3042*, Isocom Inc., 2007. [Online]. Available: http://www.isocom.com/datasheets/db91048.pdf

[3] "Demystifing the sharp ir rangers," Acroname, 2006. [Online]. Available: http://www.acroname.com/robotics/info/articles/sharp/sharp.html

[4] J. L. Jones, A. M. Flynn, and B. Seiger, *Mobile Robots: Inspiration to Implementation*. A. K. Peters, 1998.