Chapter 8: The Sensors of the robot

8.1 Introduction

Essential points:

- Sensors for our robot:
- Touch sensors
- Range IR proximity sensors
- Ultra-sonic sensors
- IR Path following sensors
- Sound sensors
- Sensors and computer:
- Analog-to-digital Conversion

Sensors are essential to robots, without them the robot would not respond to external simulations and not be able to perform useful tasks. Now we will discuss various sensors and sensing techniques to make our robot smart. An extensive discussion of this topic can be found in [1]

So what are the sensors we can use? In summary they can be classified as follows:

- Light sensors: visible, invisible
- Force sensors: touch, sound etc.
- Electo-magetic sensors: for tablets, 3D positioning etc.

Sensors are devices that convert some form of energy into electrical signals, then feed these signals to a computer for future processing. If the signal is digital it can be directly used by the computer, however, if the signal is analog, we need to convert it into digital form before a computer can understand -–it is called the analog-to-digital conversion process.

8.2 Overview of the system

In our robot only a subset of the possible sensors will be used.

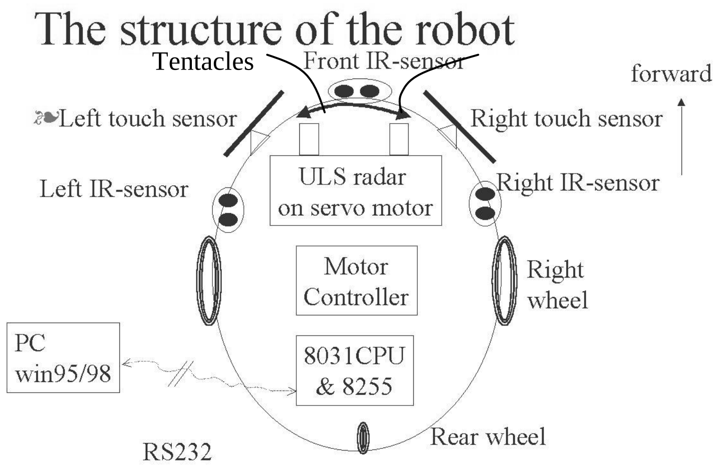


Figure 8- 1 The robot with sensors

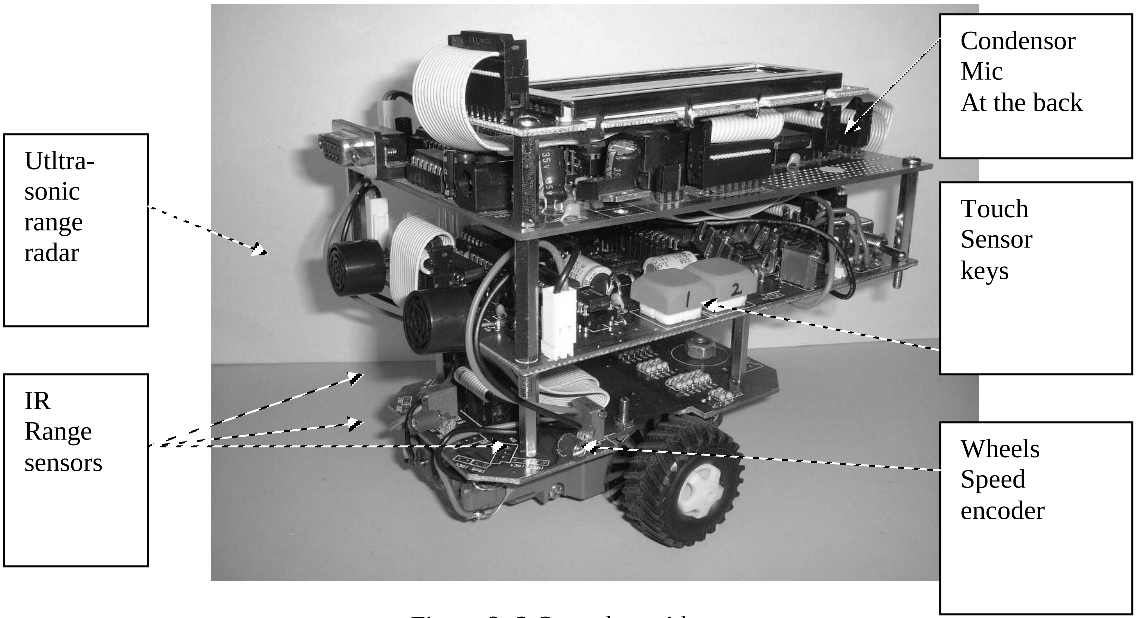


Figure 8- 2 Our robot with sensors

These include:

- Touch sensors: key switches, key pads, tentacles
- IR short range proximity sensors
- Ultra-sonic longer range sensors
- IR path following sensors
- Sound sensors

8.3 Touch sensors

As you can see from the above diagram that two touch sensors are mounted at the front of the robot. It is used to sense if the robot has bumped into some obstacles or not. The circuit of connecting these sensors is simple, which has been shown below. The touch sensors can be just two keyboard switches or micro-switches.

8.3.1 Keyboard switch:

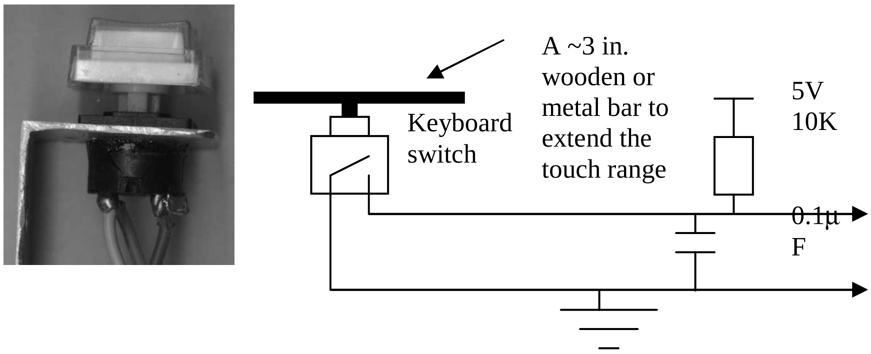


Figure 8- 3 The keyboard switch, and sensing circuit

We can simply use two low cost keyboard switches for making the touch sensors. When the switch is depressed the connection is on. The short wooden bar is used to extend the touching range. This approach is economical, however, it does require certain amount of external force to switch it on; it may damage the obstacle (if it is a fragile one) as a result. One alternative is to use a micro-switch instead.

8.3.2 Key switch array

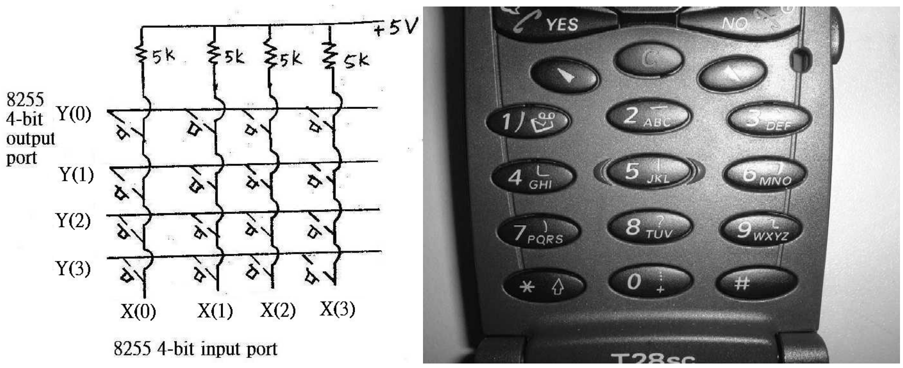


Figure 8- 4 (left) The Schematic of a key scanning keypad system of 4x4 keys using 8255 input/output ports. (right) A telephone keypad, which also uses key scanning method.

The switching system of scanning a key array is shown above, by giving different codes to the outputs and read the inputs for each case, one can deduce which key has been depressed. This scheme is used widely in making computer keyboards.

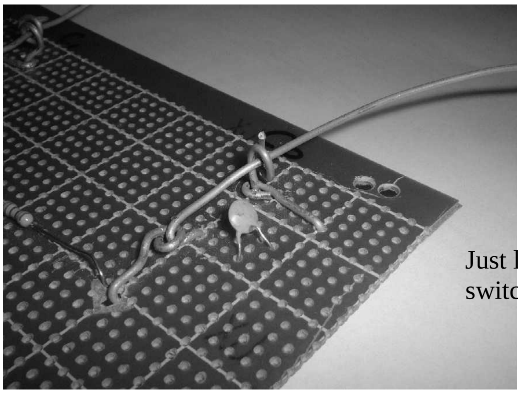
```
Key_scan_simple( )
{ unsigned char i,x,y;
      //handle denounce problem here, such as,
      //          check if the previous key press has been released or not

      //scanning for a key press
      for(i=0;i<4;i++) //4 times
      {          y=1110(B); //Y(3),Y(2),Y(1),Y(0)=1110
                  output y to 8255 output port
                  X = read in 8255 input port
                  if (X not equal to 1111(B))
                  { //a key has been depressed
                    break;
                  }
                  rotate "y" 1 bit to left, i.e. 1110 will become 1101 etc.
      }
      Find which key has been depressed by current X and Y values.
}
```

Exercise 8. 1 Exercise:

I. How to interpret which has been depressed by using x and y?

II. How to handle multiple key presses.

8.3.3 Tentacles



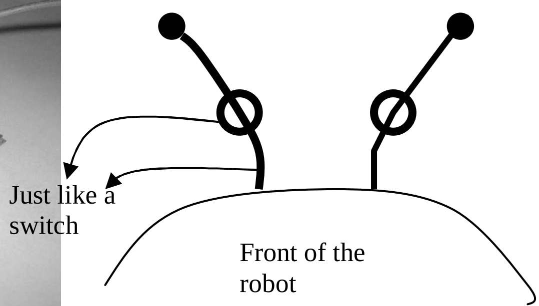


Figure 8- 5 Touch sensors using 2 pieces of metal wire

A tentacle can be made from a long copper wire inserted into but not touching a small metal ring as shown above. When the tentacle touches some objects, the copper wire has a high chance to make contact with the ring hence close the circuit. The connection would be the same for a key switch sensor.

8.4 Short Range Infrared Red (IR) proximity sensors

- IR range sensor for short range sensing
- Non touch, avoid wall banging

- IR LED/transistor used
- Schmiit trigger to reduce noise

The touch sensor described above is not much use for micro-mouse competitions and other applications since it has to touch the walls or obstacle to be effective. It may knock off the walls of the maze in a micro-mouse competition, which is forbidden. A more sensible arrangement is to use non-invasive techniques that no touching is required. Infrared red proximity sensor is a good choice.

In an IR sensing system, there are two important components: IR emitters and receivers. One simple arrangement is to use an IR emitter to emit IR light to an object and the receiver is used to pickup the reflection from the reflective object.

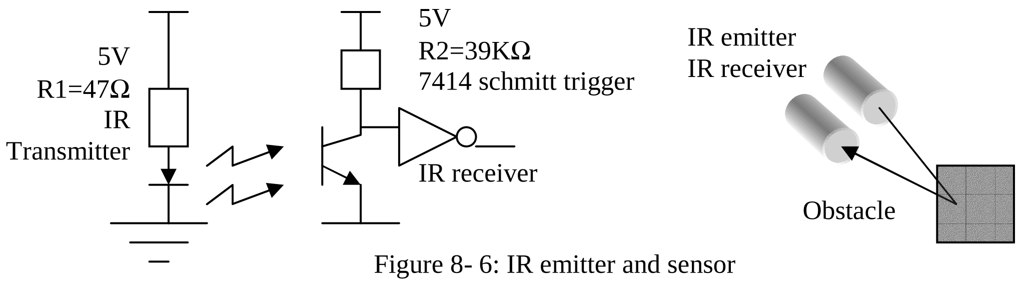


Figure 8- 6: IR emitter and sensor

The IR emitter is a light emitting diode (LED), when passes current emits IR light. To control the light intensity and limit the current flow to a level not to damage the IR transmitter, we choose the limiting resistor to be 47Ω. So the current is about (5-0.7)/47 ~ 91mA.

For the receiving side, the IR receiver will be turned on when IR light is received. The Schmitt trigger inverter will give a high output. The 39KΩ resistor is used to bias the transistor, while the Schmitt trigger inverter is used to filter noise. We can also use a variable resistor instead of a fixed one as R2 for adjusting the sensitive of the sensor.

There are two applications for this short-range obstacle sensor. First it is used to detect obstacles at the front of the robot. Second it is used to detect the rotational speed of a wheel by sensing the on/off patterns on a disk attached to the wheel. Such a scheme was described in the last chapter.

This simple architecture is workable but only under the conditions that the measuring range is short (1~3 in.) and no direct external light source falls onto the receiver, which may cause false reaction at the receiver. A more sophisticated scheme is the frequency-modulated method, which may reduce the effects of the problems mentioned above.

Exercise 8. 2 What is Schmitt trigger logic? Why do we need a Schmitt trigger inverter here?

8.5 Frequency modulated Infrared Red (IR) detector

- Frequency modulated IR link performs better
- Enhance range
- Reduce noise
- Used for remote control of home appliances too

In a frequency modulated scheme the IR transmitter flashes light at a particular frequency. And the receiver is also tuned to receive only light with that on/off frequency, that means only when such frequency modulated light occur it will switch on its output. The above circuit will then be modified as follows.

It is noted that a 40KHz frequency modulated IR sensor GP1U52X (which contains a high-gain frequency-tuned amplifier) from the company Sharp is in use.

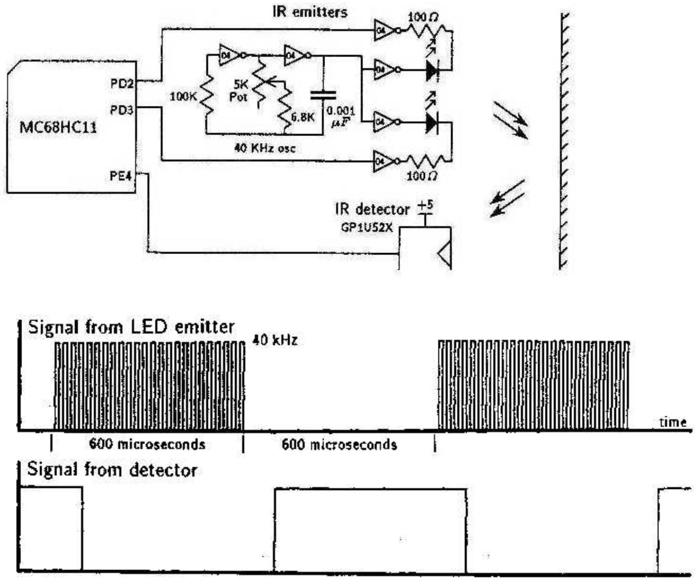


Figure 8- 7 show the light modulated IR obstacle detection scheme.

The reason for the superiority of this scheme over the un-modulated one is that it has a frequency-tuned high gain amplifier at the receiver. Only IR light switching at 40KHz will trigger the receiver to response. Other external lights (e.g domestic light bulbs or the Sun) do not usually contain that frequency content. In fact such a method is widely used in the IR remote control of home appliances, by transmitted code from the handheld IR emitter, an MCU at the receiver of an appliance, e.g. a television, will operate as instructed. The control range can be as far as 10 meters or more.

8.6 Using analog-to-digital converter to measure the distance between the light sensor and the obstacle.

The above methods are useful to detect the occurrence of obstacles, however, it will not tell you how far the obstacles are. Since the analog voltage output at the IUR sensor is inversely proportional to the distance between the sensors and the object, we can use this information to have a more accurate range measurement. Now we will introduce the concept of analog-to-digital conversion. An analog-to-digital converter (ADC)is a device for interfacing the analog world to the digital world. A typical ADC is the ADC820 [ref]. For example, in an application, the input of the ADC is connected to the IR sensor output. And the output of the ADC is connected to the 8255 of our SBC. By programming the 8255 to receive digital codes, we can read out the IR sensor output hence the range data.

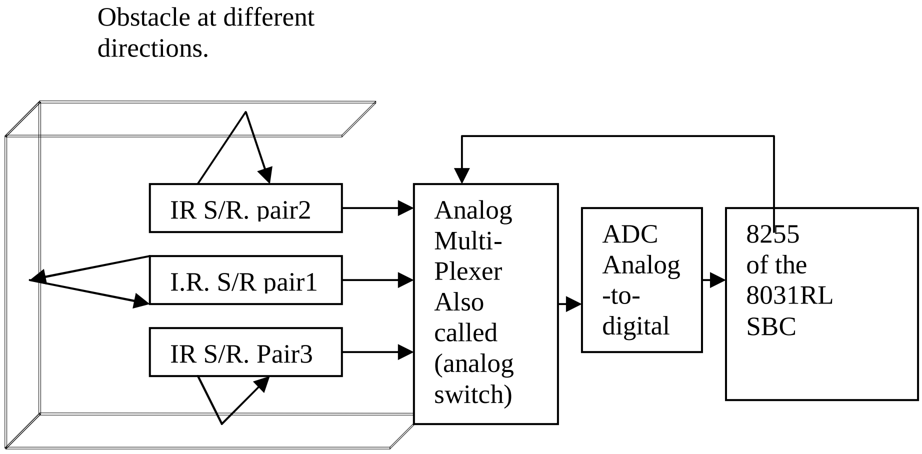


Figure 8- 8 channels range measurement using IR, multiplexer and ADC.

In order to enhance the sensory capability of the robot, we would like to have not just one such IR range sensor but three or more IR sensors with range measurement for the robot. We can duplicate multiple sets of IR sensor and receiver (S/R) pairs and for each channel use an ADC to converter data. However, a more cost effective method is to have one set of ADC to converter all IR channels. Since each IR sensor output is an analog voltage we will use a device called an analog-multiplexer (or called an analog switch) --CMOS 4051 to handle the multiplexing job. The circuit is shown here.

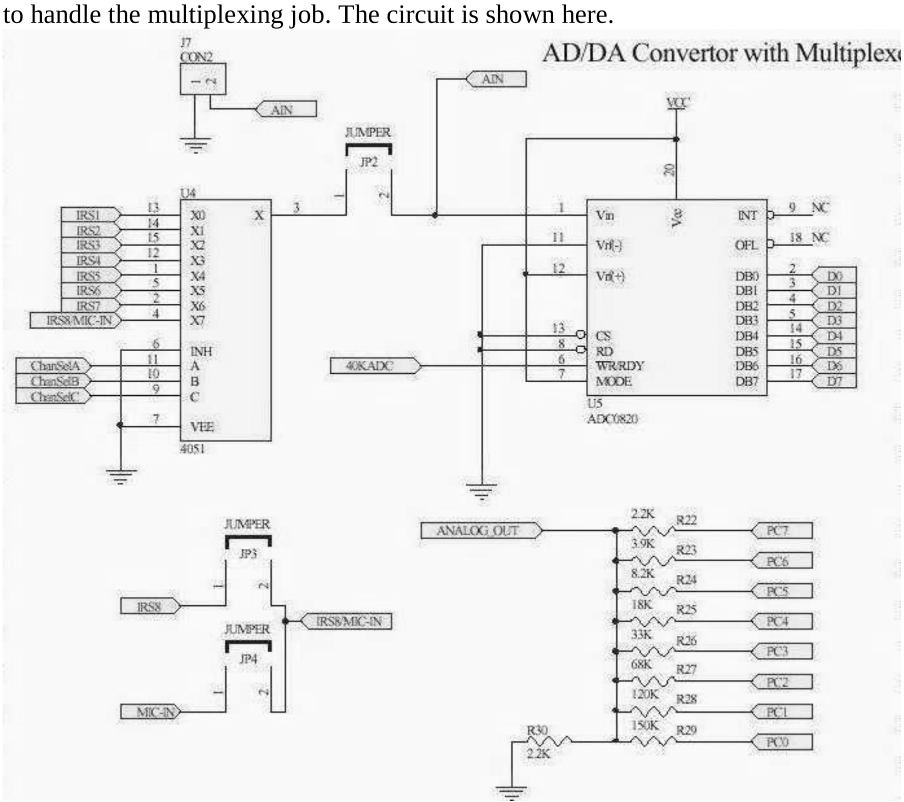


Figure 8- 9.The analog multiplxer and ADC circuit for multi-channel IR range measurement.

Ir1,-IR7 are 7 IR receiver outputs on the robot PCB. The channel section bits (ChanSelA, B, C) are actually three bits from the 8255 of the 8031RL-SBC. Hence the program for reading IR range data is as follows.

```
Main()
{       Init. System and 8255.
        Select channel by setting up the code for ChanSel A, B, C by the 8255 output port;
        Read 8255 port for the ADC.
}
```

Now the robot does have some sense of the environment it is living in. By careful using these data we can ask the robot to navigate in a maze without bumping into the walls.

8.7 IR guided Path following sensors

We can also use IR sensors to make the robot to follow predetermined path.

For example, we can use IR sensing methods (frequency modulated or not) for making the robot to follow a white line on a black floor. This is useful in an environment where we want the robot to drive through a predetermined path, e.g. in a factory or an office area for delivering goods. For example, in the following simple scheme, a white line is drawn on a floor of dark color. We set the IR receiver at the middle and two independently controlled IR transmitters (LED) are on the two sides. When the IR-LED on the right is ON and the receiver does not receive any reflected light, the robot is off course to the right. We then turn ON the IR-LED on the left to see if the robot is off course to the left using a similar method.

Of course more sensors and sophisticated algorithms should be used to make the system more robust.

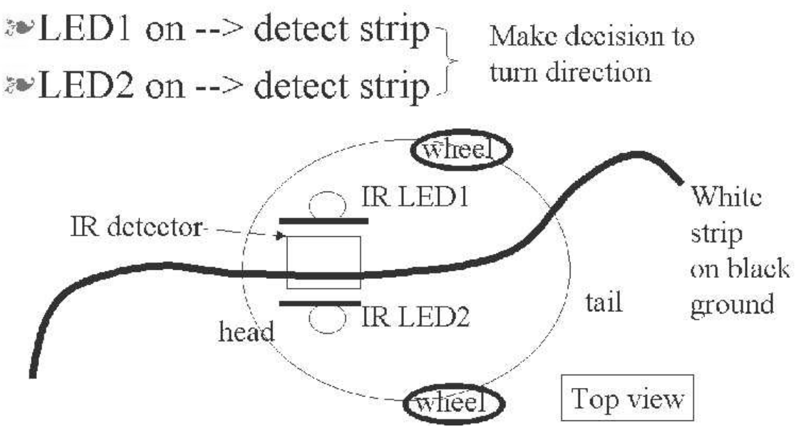


Figure 8- 10 Path following method

8.8 Sound sensors

- Types of microphones
  - Moving coil microphone
  - Condenser microphone

- Use ADC to convert to digital code
- Input to Speech Recognition system
- Clipping for simple sound detection

The intention of having this kind of sensors is to give an ear to the robot, so that it can hear sound. We are sort of playing GOD here for we are molding some creatures of our own. However, it is not easy at all, as our scientific knowledge has not been advanced to such a stage that we can make anything we want. In particular we cannot offer speech recognition capability comparable to human to our robots at this stage. Nevertheless, sound or noise recognition for detection of hand clapping or whistle may be possible. Here we will begin to discuss a simple sound detection module using a microphone inserted to the robot system.

8.8.1 Microphone

First we should study the microphone we are going to use. There are two types of microphones we can choose.

8.8.1.1 Moving coil

A moving coil microphone has a flat circular membrane connected to a moving coil that is inserted in a magnetic field. When the membrane vibrates in resonance with the external sound, the moving coil in the magnetic field generates a small electric voltage corresponding to the sound wave.

The advantage of this type of microphone is it generates electrical on its own; no battery is required, however the disadvantage is it has very small output level (~1mV peak-to-peak) so that a microphone amplifier is required. The frequency responses is round 80~15KHz with low distortion.

See http://www.alpeda.com/fr_809.htm for more information

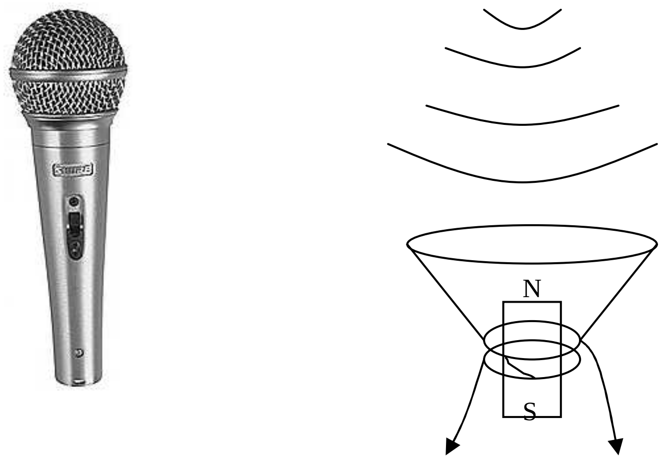


Figure 8- 11 A moving coil microphone form the company Shure.

(http://www.thecorestore.com/shmic.html) frequency response 80~14KHz

8.8.1.2 Condenser microphone

A condenser microphone is a capacitor with one side attached to a vibration diaphragm. When the diaphragm vibrates according to the incoming sound, the capacitance changes, so by measuring this change one can deduce the sound signal. Usually a small (build-in with the microphone) amplifier is attached to the microphone to give an output of about 10mV peak–to-peak, thus a small voltage supply for the build-in amplifier is required. For the performance, it usually has a wide range of frequency responses (up to 20~20KHz) but the distortion is higher than a moving coil microphone. Because of its small size and superior performance it is widely used in Audio system such as Mini-Disk (MD) recorders, PC sound card systems etc. Therefore we choose to use it in our robot.

Condenser microphone are also available at low cost, for less than HK$10 you can have a two terminal condenser microphone. An application diagram is shown below.

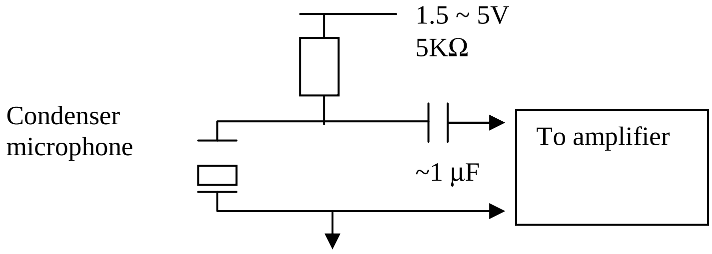


Figure 8- 12 Condenser microphone and its interface circuit

8.8.1.3 Amplifier for condenser microphone

The outputs of the microphones of either the moving coil or the condenser types are very small. We need to amplifier it to a substantial level (around ~4.5V peak-to-peak) to be used at a later stage. A simple op-amp for the condenser microphone using the popular 741 is recommended here. Now the output can be fed into the input of an analog-to-digital converter for further processing.

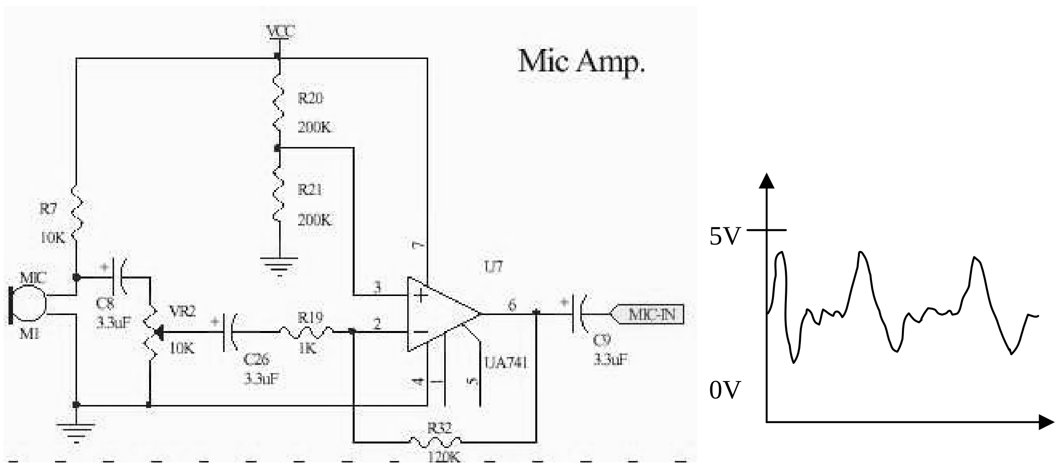


Figure 8- 13 Condenser microphone amplifier circuit, and the diagram showing the output swing around the biased 2.5V

In the above circuit R32 (feedback resistor) can be adjusted to alter the gain of the amplifier, the gain is about R32/R19, and in the above case it is 120. So be careful, for a high gain amplifier such as this, positive feedback and noise may create problems.

Also from the diagram above the non-inverting input of the op-amp is biased at 2.5V, so the amplifier can have a full swing with its output centered at the middle, and the output is at 2.5V when the microphone receives no sound.

8.8.2 Sound level detection and level shifting circuit

The analog signal at the output of the microphone amplifier can be transformed into digital code by an analog-to-digital converter ADC. The digital code will be the source of automatic speech recognition and other useful applications, e.g. digital voice recording.

However, this will involve more complicated hardware. A simple and useful application of the condenser microphone is the sound level detector. Such as a simple hand clapping recognition is enough, therefore the following circuit is recommended.

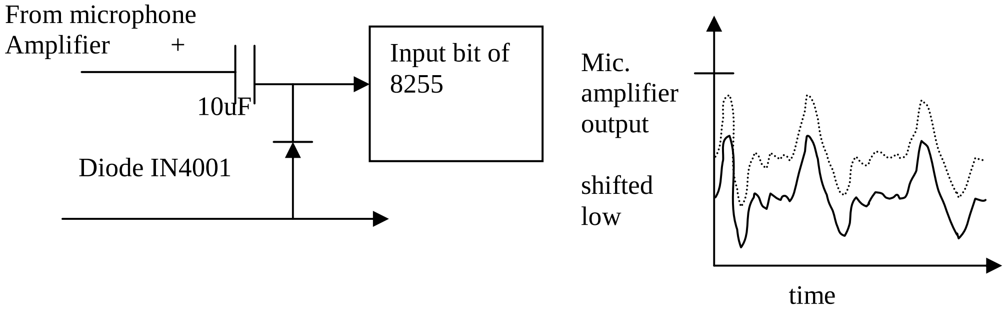


Figure 8- 14 The level shifting circuit for sound level detection

It is a level shifting circuit that shifts the output signal of the microphone amplifier towards ground. The signal lower than 0.7 is clipped but it doesn't matter because what we want to know is whether there is output energy at the output or not. If sound occurs, it will create some voltage for the 8255 to capture. Of course the sound output if clipped is very unpleasant to listen to (if you bother to connect this output to an earphone or an audio amplifier.).

8.8.3 A digital sound recorder using ADC and DAC

Imagine you have a robot that can listen to you verbal command. Then you can talk to your robot and ask it to it to move forward, backward and it can do it accordingly. Is it possible for our robot to do so? I think the answer is yes, but it is not easy. The first stage is of course to have the raw speech data by capturing speech signal by a microphone, amplifies it, converts it into digital format and stores it in the computer. Then, use an intelligent program to analysis the data and find out what the "master" (– you) has been said. To demonstrate the idea, we have setup an experiment to have the preprocessing of this speech recognition, namely a digital recorder. It records a short segment of the speech signals, stores it and replays back to the user, it is a simplifier demonstration to show that our robot does have some sort of capability to listen to human speech.

In fact we have all the circuits in out robot PCB to handle this experiment.

- The microphone: This is shown in a previous circuit that uses a uA741 op-amp to amplifier the signal up to a higher level.
- The ADC circuit –An ADC820 circuit is used to convert speech signal input into digital form.
- An output Digital-to-Analog converter DAC that converts digital code into analog voltage, the voltage will be fed to an audio power amplifier (LM386) to drive a speaker.

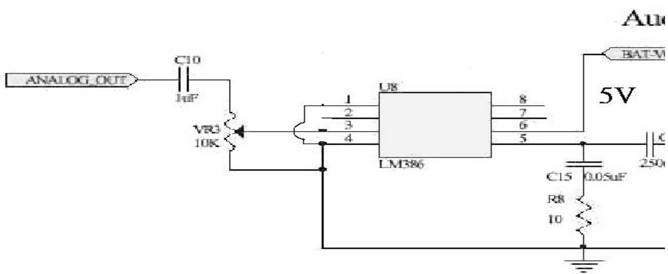


Figure 8- 15 Power amplifier for speaker circuit

The only element missing for this digital sound recorder is the program. The are two method to do the job.

- Polling method

```
xdata unsigned char ram_store[N], i;
record //sampling  record and playback at one go
{
      for(i=0; I < N ; i++)
      {
            ram_store[i] = read_in_sound_code_from_8255;
            output_to_dac = ram_store[i];
            delay(); //this determines the sampling rate
      }
}

playback() // playback what has been rcordered
{
      for(i=0; I < N ; i++)
      {
            output_to_dac = ram_store[i];
            delay(); //this determines the sampling rate
      }
}
```

This method has a serious problem of the sampling rate, which cannot be controlled very accurately because interrupts may occur in side the program loops. If the sampling rate is chnaged during record and playback the sound tone may change.

- Interrupt method

Exercise 8. 3

(I) *Write the program for the interrupt method.*

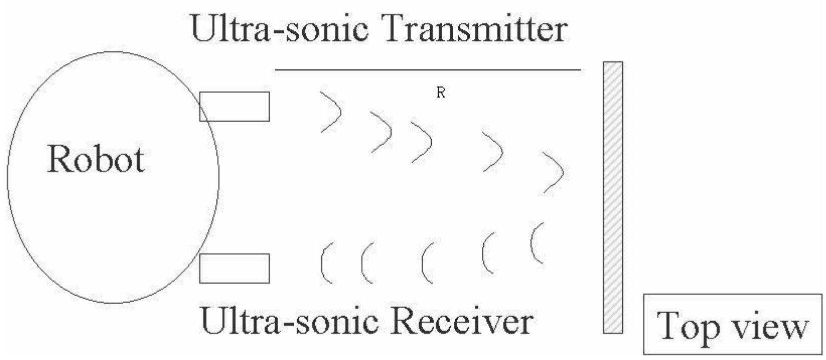
(II) *Write the algorithm to detect the sound of a handclap or a whistle sound.*

(III) *What are the elements we need to implement a speech recognition system?*

8.9 Ultrasonic radar system

- A non invasion range detection system
- Batman’s radar system

The proximity range sensor using IR discussed earlier has a short sensing range of about a few inches. However, if we have an obstacle of a few meters away, an ultrasonic radar system is more effective. As inspired by bats, such a an ultrasonic radar system sends ultra-sonic wave to an obstacle and listens to the echo sound bounced back to the receiver. By measuring the time-of-flight (T_{delay}) that the sound transmitted from the transmitter to the receiver, one can deduce the distance between the obstacle and the sensors by the

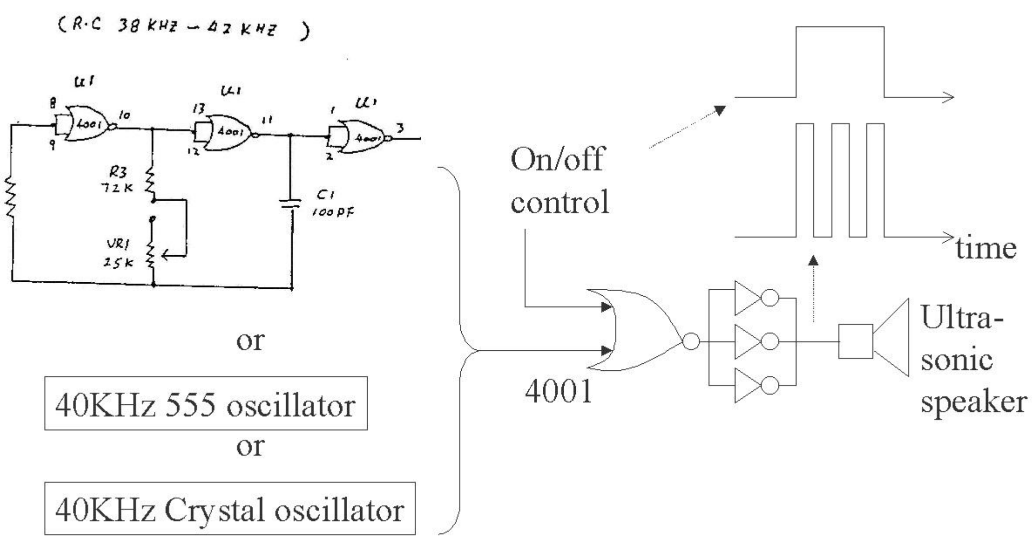


following formula.

R (distance from robot to obstacle) = T_{delay} * (Velocity of sound) /2 ,

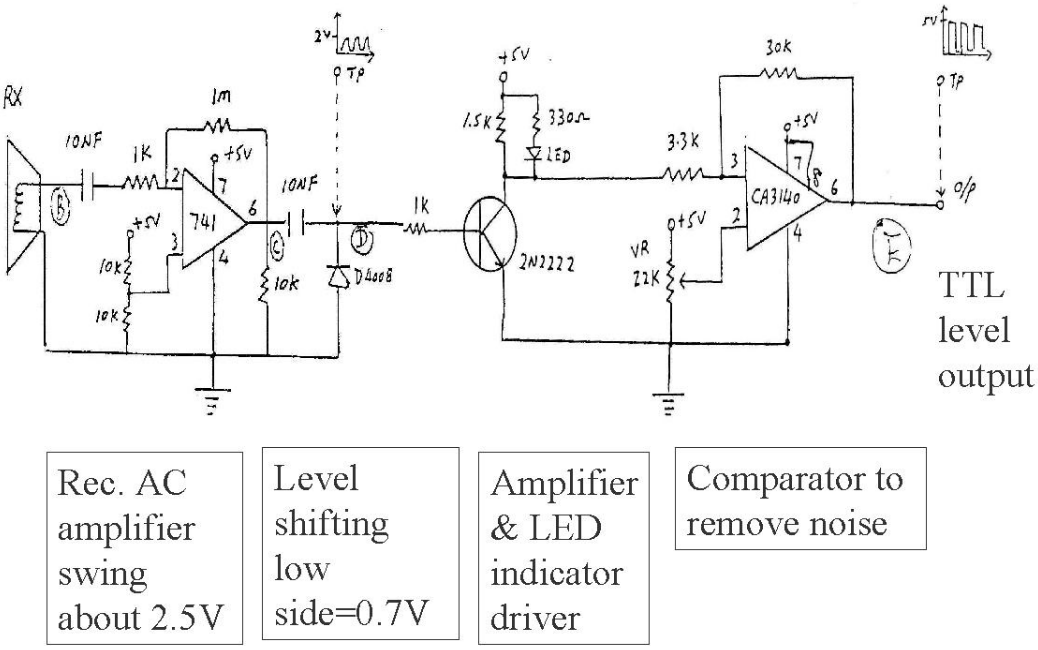
And Velocity of sound is about 330 m/s.

8.9.1 Ultrasonic sound transmitter (RX-TX)



We have three different methods to generate a 40KHz signal and the on/off control governs whether this 40KHz signal should be sent to the Ultrasonic transmitter (speaker) or not. In fact by carefully switching the on/off control we can send out a coded message using ultrasonic sound, some remote control systems are using this method.

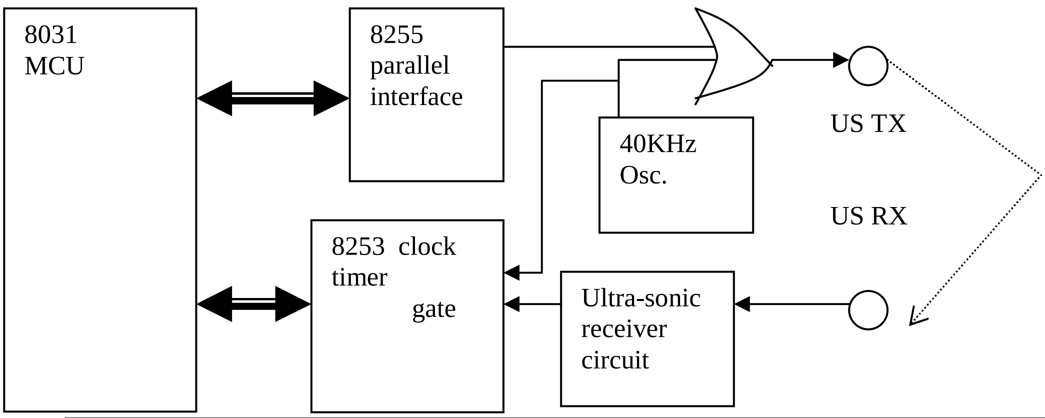
8.9.2 Ultrasonic sound receiver (US-RX)



This ultrasonic receiver system transforms the sound wave into a TTL output signal.

8.9.3 Ultrasonic- radar control using 8253

Using the above transmitter and receiver, one can design a simple radar system as follows.



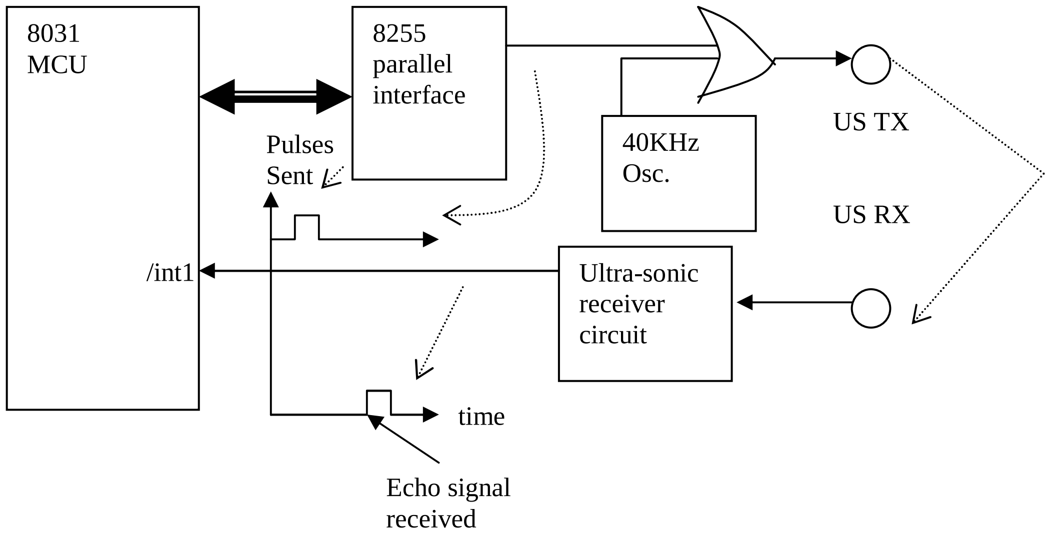

```
Algorithm_radar1 ( ) // by polling method
{     instruct the 8255 to send out pulses;
      start 8253 counter;
      //loop
      wait until (gate is set; echo has come back)
      read 8253 counter ;
}
```

Figure 8- 16 Block diagram and algorithm for the 8253 based ultra-sonic radar system

The actual design of the ultra-sonic radar system using 8253 is left to be an exercise for students.

8.9.4 Ultrasonic- radar control using 8031 interrupt and its internal timer

We found it is also possible to use the 8031 interrupt and internal timer for making the radar system.




```
Algorithm_radar2 ( ) // by interrupt and timer method, tested with good result
{     initialize 8031_internal_timer interrupt;
      instruct the 8255 to send out pulses;
      start 8031_internal_timer; //now the 16-bit internal timer will start to count at 1MHz;
      //loop
      wait a while; // wait a little longer than the echo is expected to arrive
      read 8031_internal_timer value; //this is the result, you convert it into distance
}
//ISR ///////////////////////////////////////////////////////////////////////////////////////////
isr2_type2_for_timer1_for_radar2 //when it occurs, echo pulse has arrived
{
   Stop 8031_internal_timer;
}
```

Figure 8- 17 Block diagram and algorithm for the 8031 interrupt and internal timer based ultra-sonic radar system

Exercise 8. 4

I. *Compare the two methods Algorithm_radar1( ){using 8253} and Algorithm_radar2( ) {using internal timer interrupt shown above}.*

II. *For Algorithm_radar2( ), if the object is 3 meters away and the speed of sound is 300m/s, what is the time-of-flight of the sound wave from the transmitter to the receiver?*

III. *What is the result at the 8253 count register?*

IV. *What is the accuracy (+-meters) of this design? What factors determine the accuracy of this system?*

8.10 Temperature sensing

Temperature sensors are available for measuring the temperature of the surrounding environment. The output voltage level of a temperature sensor corresponds to the temperature sensed. We also need an ADC to converter the sensor output voltage into digital code in order to be understood by a computer.

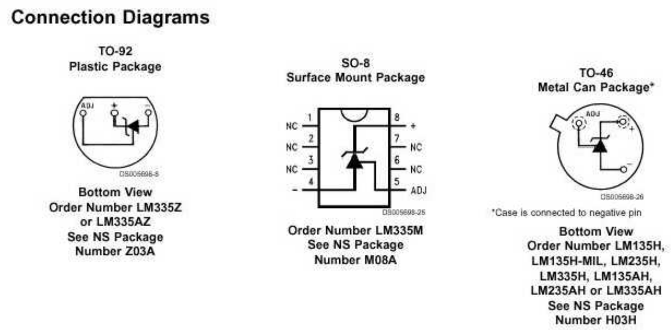


Figure 8- 18 LM135 from datasheet of LM135 of National Semiconductor [4]

8.11 Electronic compass

Such a device is available at about HK$1000 each, which can measure the orientation of the robot using the magnetic field of the earth. We have tested and the accuracy is about 1 degree. As shown in the figure, it has two magnetic sensors placing perpendicular to each other, by sensing the difference of magnetic field strength of two orthogonal positions, one can deduce the orientation of the sensors with respect to the magnetic field of the globe.

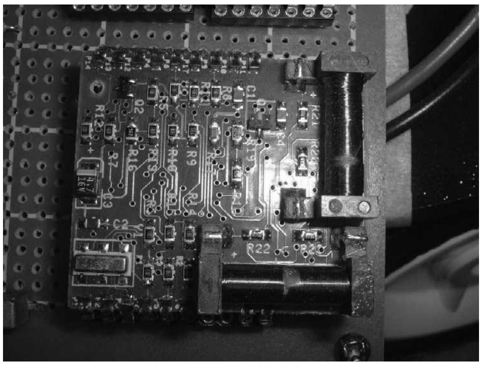


Figure 8- 19 A magnetic compass module vector 2X from the company "Vector electronic modules"

8.12 Conclusion

A number of different sensors: range sensors; touch sensors; electronic compass and ultrasonic radar systems have been studied in this chapter.

8.13 Reference

1. H.R. Everett H.R. *Sensors for Mobile Robots, theory and application* published by AK Peters.

2. Microphone characteristics http://www.alpeda.com/fr_809.htm

3. 8253/4 data sheet from http://support.intel.com/support/controllers/peripheral/index.htm

4. Data sheet of LM135 from http://www.national.com/catalog/