An Eye for Distance

Optical triangulation with the ATM18 board

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People don't come with built-in rulers, but if we need to know how far away an object is, we can estimate the distance (and we do it all the time). However, how can a robot determine the distance to an object and do so with sufficient accuracy?
In this article, we examine the various methods that can be used and describe a distance measuring system that uses an infrared sensor and the ATM18.

Our ability to estimate distances accurately depends on many factors, such as how well we can see the remote object and whether we know the size of the object and other objects in its vicinity. In any case, our estimates are approximations and rarely exact. However, a moderately accurate estimate is usually sufficient for finding our way around in our surroundings. Things are different with a robot, for example when it has to adjust its speed and acceleration while approaching an object located 80 to 150 centimetres away.

We started by taking a closer look at various methods for determining the distance to an object. The following three methods are apparently the most important:

1. Propagation time and relative phase measurements using radio signals
2. Optical measurements (including laser measurements)
3. Measurements using ultrasonic signals

With regard to the last of these methods, we would like to make a small digression here to the animal world. As you know, bats use various sonar techniques with fixed frequencies and varying frequencies that yield a constant reflected frequency from stationary objects. The results are calculated so fast that these small aerobatic artists can navigate through narrow caves in full darkness with incredible virtuosity, and they can locate and capture insects in full flight. Although artificial ultrasonic measuring devices employ methods that are similar to those found in the animal world, our technology falls far short of the capabilities of natural sonar systems.

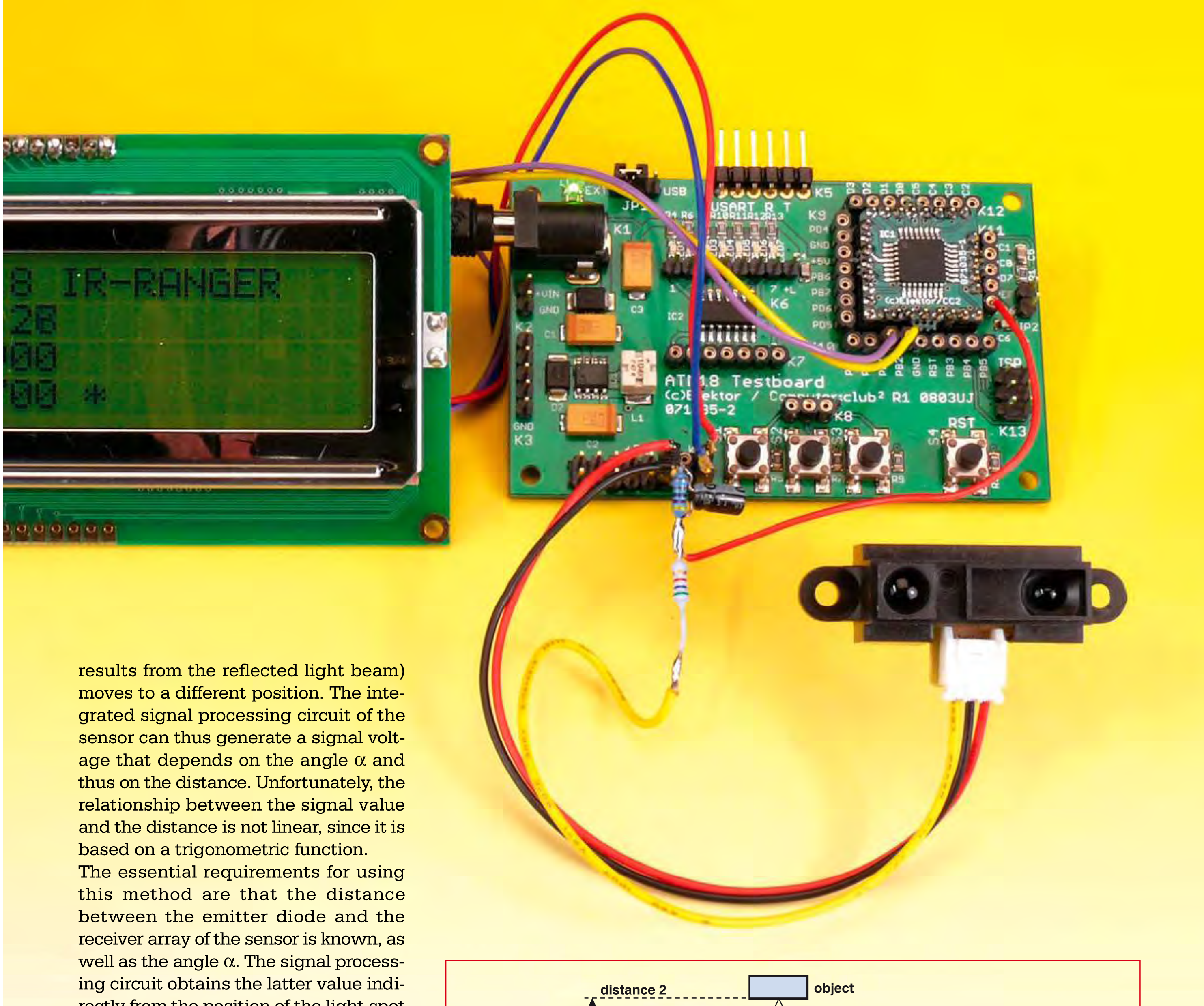
Every method has its advantages and disadvantages. Ultrasound is very sensitive to reflections and the physical properties of the atmosphere. Measurements based on the propagation time of radio signals require lightning-fast signal processing circuitry.

Optical triangulation [1] is a commonly used method for measuring distances with light.

Angle measurement

Optical triangulation is based on measuring the angle between emitted and reflected light beams instead of the propagation time of a light signal. Professional equipment uses laser diodes for this purpose in order to obtain high accuracy, but a normal LED can be used for relatively short distances if high accuracy is not necessary.

The operating principle of optical triangulation is shown in **Figure 1**. The LED at the left end of the sensor acts as the emitter. A precision lens forms the light emitted by the LED into a narrow beam that is reflected from the target object. A portion of the reflected light enters the lens of the receiver section of the sensor (at the right in the figure). The angle of the reflected light beam depends on the distance between the sensor and the target object. A 'position-sensitive detector' (PSD), or in other words a linear-array CCD IC, is located behind the receiver lens. The receiver lens focuses the reflected light beam into a spot that illuminates as few of the light-sensitive cells of the CCD array as possible, so that its position can be determined. If the distance to the target object changes, the angle α of the received light beam also changes, and a different part of the light sensor is illuminated (**Figure 2**). This clearly illustrates the operating principle: when the distance changes, the spot of light on the PSD (which



results from the reflected light beam) moves to a different position. The integrated signal processing circuit of the sensor can thus generate a signal voltage that depends on the angle α and thus on the distance. Unfortunately, the relationship between the signal value and the distance is not linear, since it is based on a trigonometric function.

The essential requirements for using this method are that the distance between the emitter diode and the receiver array of the sensor is known, as well as the angle α. The signal processing circuit obtains the latter value indirectly from the position of the light spot on the PSD. Using this information, the sensor's integrated signal processing circuit generates a signal that is available at the sensor output. Another consideration is that this method is only suitable for short distances (up to a few metres) because the sensitivity depends on the distance between the emitter and receiver sections, which are both contained in a small package.

If you want to determine the distance from the voltage generated by the sensor, you have to do some calculations. The following trigonometric formulas can be used to determine the distance $x - x_0$ from the measured distance $x' - x_0'$:

$$\tan\delta = \frac{x' - x'_0}{f} \rightarrow \tan\alpha = \frac{x_0}{D}$$

$$x = D \cdot \tan(\alpha + \delta) = D \cdot \frac{\tan\alpha + \tan\delta}{1 - \tan\alpha \cdot \tan\delta}$$

$$x = D \cdot \frac{\frac{x_0}{D} + \frac{x'-x'_0}{f}}{1 - \frac{x_0}{D} \cdot \frac{x'-x'_0}{f}}$$

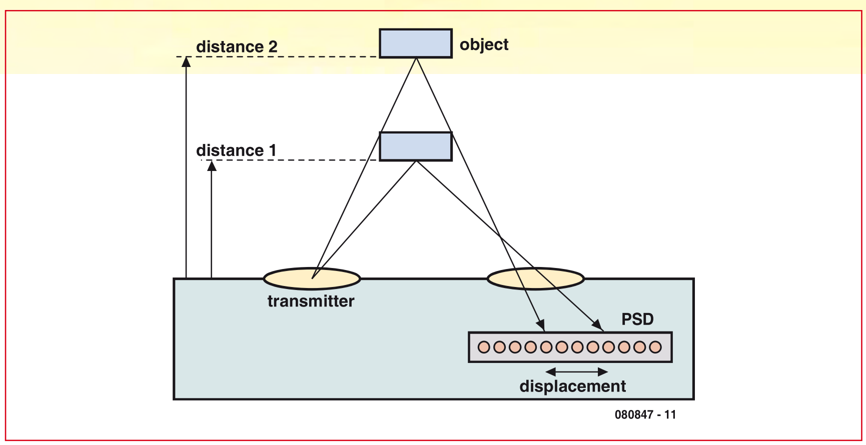


Figure 1. Distance measurement using optical triangulation.

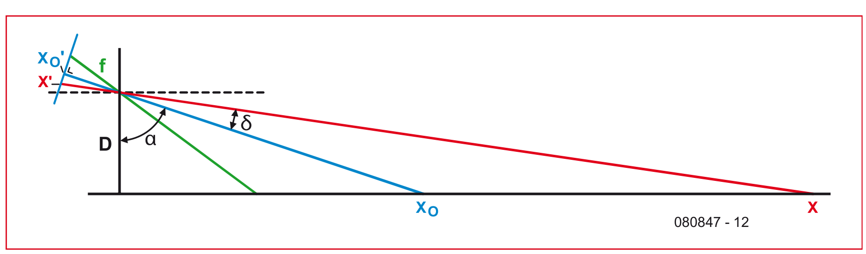


Figure 2. The distance $x - x_0$ can be determined from the measured distance $x' - x_0'$ by using trigonometry.

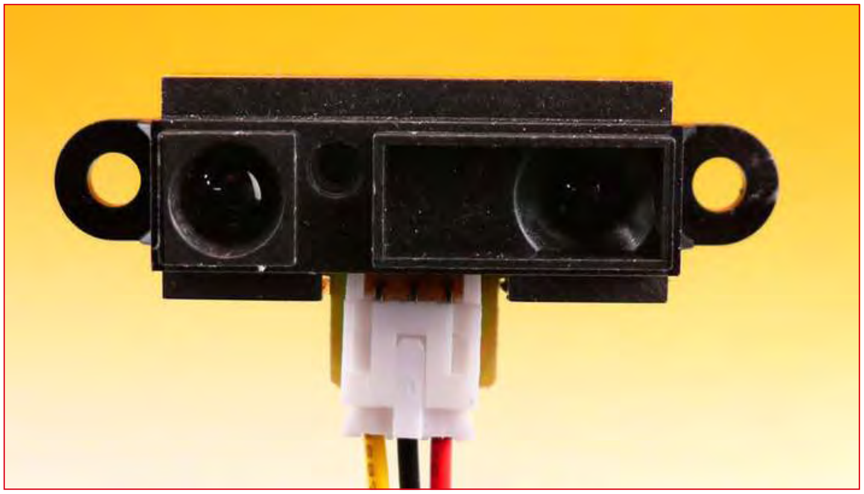


Figure 3. Sharp infrared distance sensor.

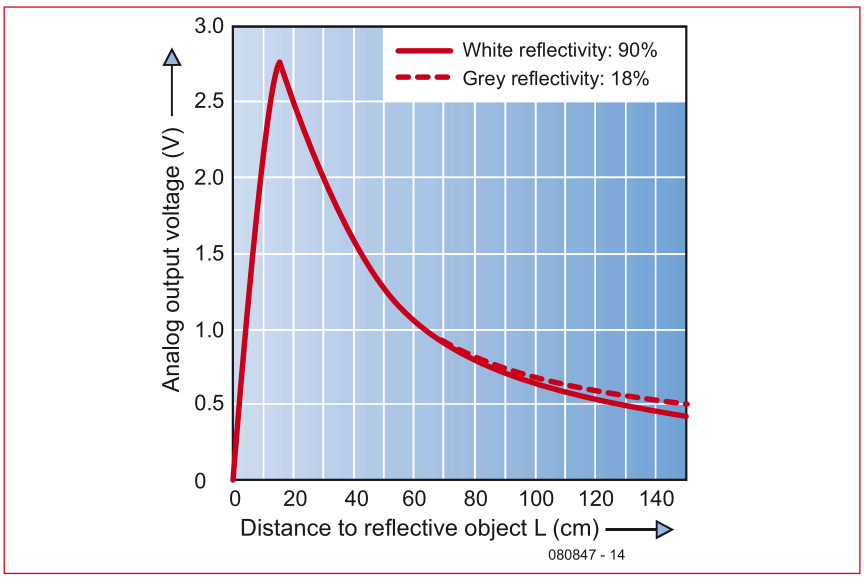


Figure 4. The relationship between output voltage and distance is non-linear.

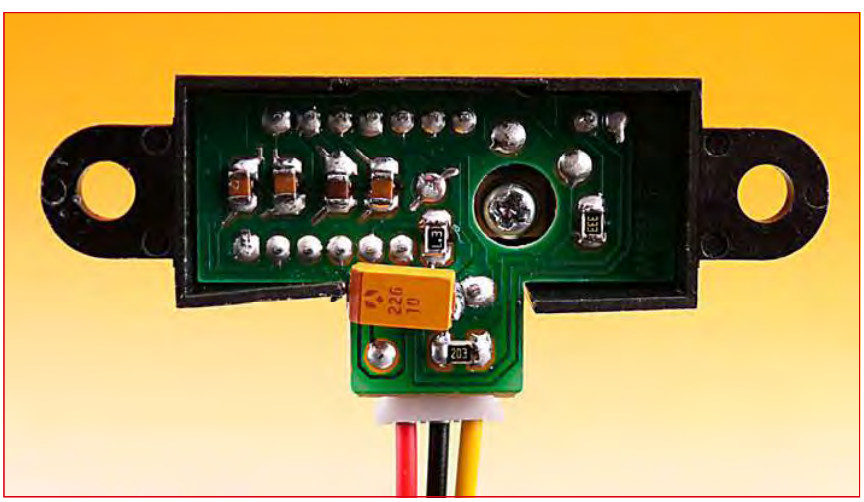


Figure 5. The sensor needs an additional SMD electrolytic capacitor for decoupling.

From the final formula for calculating the value of x, it should in any case be clear that our little 8-bit microcontroller has far too little processing power for continual measurement of the distance to any given object. There are other methods that can be used to determine the distance from the sensor output voltage without using a lot of processing power, but we don't want to get bogged down in theoretical aspects here. What matters now is putting the theory into practice!

IRDMS in practice

The focus of this project is using infrared distance sensors made by the Japanese manufacturer Sharp [2]. They go by the moniker 'IRDMS', which stands for 'infrared distance measurement sensor'. There are two different sorts of IRDMS sensors. One sort has digital outputs with an internal comparator set for a specific distance [3], while the other sort has analogue outputs. Here we use only sensors with analogue outputs. Several sensors suitable for different distance ranges are listed in **Table 1**. For our experiments, we selected the GP2Y0A02YK0F, which is intended to be used with distances of 20 to 150 cm. However, any other type listed in Table 1 can also be used, so you can select the type that best suits your particular application.

As you can see from **Figure 4**, the sensor output signal is highly non-linear. The distance cannot be derived directly from the signal without linearisation. However, this is not necessary for our initial experiments.

In theory, all you have to do to obtain a sensor signal with a range of up to approximately 2.7 V is to connect a 5-V supply voltage to the sensor. The IR diode operates in pulse mode and emits short, powerful flashes, which create a high peak load on the power supply. It is thus recommended to connect an electrolytic decoupling capacitor close to the sensor. Incidentally, the emitted light is in the near infrared range and is just barely visible to the naked eye in a dark environment, but it is readily visible on the monitor of a digital camera.

The internal linear array CCD has approximately 100 active pixels. As a result, the level of the output signal changes in steps of approximately 20 mV. A small ripple voltage with around the same amplitude is superimposed on the output signal, so a low-pass filter is a good idea. The 10-bit A/

D converter of the Mega88 has a resolution of around 5 mV with the external 5-V reference voltage, which in theory is adequate for this application. However, the C code developed for this project selects the microcontroller's internal 1.1-V reference voltage, which yields a resolution of approximately 1 mV. Caution: make sure that REF jumper JP2 is **not** fitted.

A voltage divider consisting of a 5.6-kΩ resistor and a 4.7-kΩ resistor must be connected ahead of the input to match the signal to the measuring range. With this arrangement, the measuring range of the microcontroller extends to 2.4 V. A 1-µF capacitor connected across one leg of the voltage divider lets it act as a low-pass filter as well.

The additional hardware is quite minimal. Aside from the two resistors for the voltage divider, you only need two capacitors. First you have to solder a capacitor with a value of 10 to 100 µF as close as possible to the sensor. It's beyond us why Sharp didn't simply include this on the PCB in the sensor package. **Figure 5** shows this 'user enhancement' implemented with an SMD capacitor fitted directly to the PCB.. If you don't want to monkey with the sensor PCB, you can fit a small electrolytic capacitor externally, which means soldering it to the pins – but keep the leads as short as possible. Then you have to put together the combined voltage divider and low-pass filter, which as previously mentioned consists of a 6.8-kΩ resistor and a 4.7-kΩ resistor (preferably with a tolerance of 1% or better). Then solder a 1-µF capacitor across the 4.7-kΩ resistor (see **Figure 6**). Connect the junction of the voltage divider to the AD6 input. The full circuit on the prototyping board is shown in **Figure 7**. Connect buttons S1, S2 and S3 to PB3, PB4 and PB5, and connect the PC0 and PC1 outputs to any desired inputs (one each) of the ULN 2003 so they can be used to drive the associated LEDs (these connections are not shown in

Table 1

Sharp IR distance sensors with analogue outputs, suitable for various distance ranges.

Type designation	Range [cm]
GP2D120XJ00F	4–30
GP2D12J0000F	10–80
GP2D15J0000F	10–80
GP2Y0A02YK0F	20–150
GP2Y0A710K0F	100–500

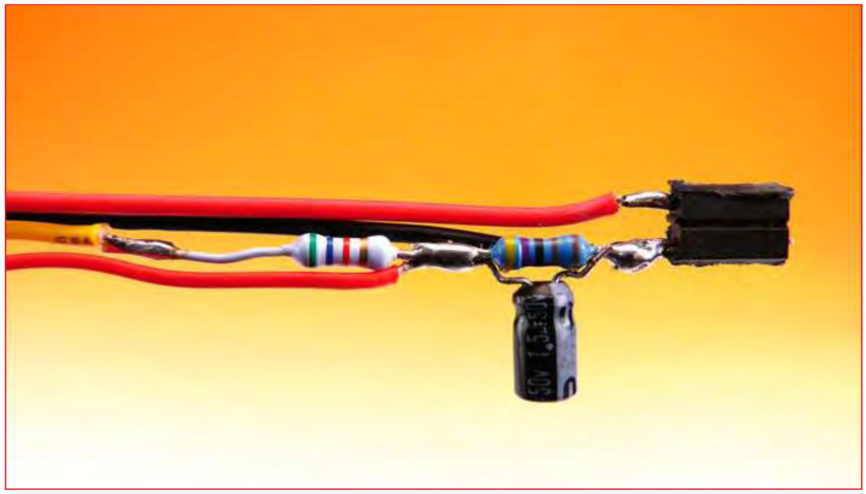


Figure 6. Two resistors and an electrolytic capacitor form a combined voltage divider and low-pass filter for the sensor signal.

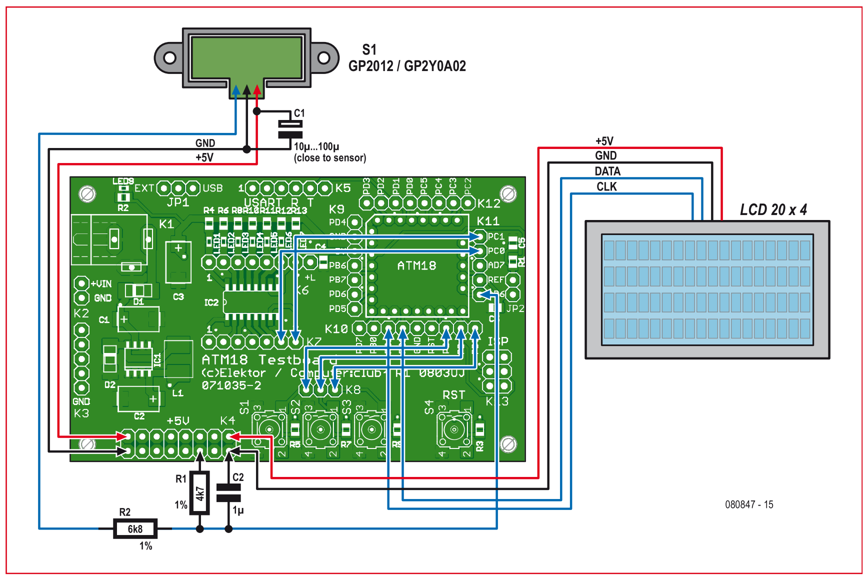


Figure 7. All connections at a glance.

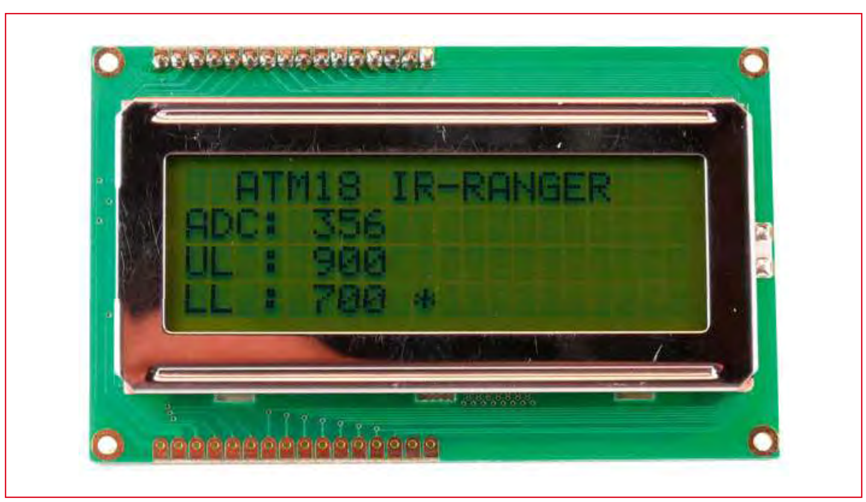


Figure 8. Displayed sensor values.

Listing 1

Distance calculation in Bascom

```
Sub Calculate_s
    D = Getadc(6)
' U = D/1023 * (4.7+5.6)/4.7
    'U = D * 5
    U = D * 1.1
    U = U * 10.3
    U = U / 4.7
    U = U / 1023
    'Print U
'           0.008271
  + 939.6 x Us
' S =  ----------------
  -----------------
'     1 - 3.398 x Us +
  17.339 x Us x Us
    If U > 0.4 Then
      S1 = 930.6 * U
      S1 = S1 + 0.008271
      S3 = U * U
      S3 = 17.339 * S3
      S2 = 3.398 * U
      S2 = 1 - S2
      S2 = S2 + S3
      S = S1 / S2
    Else
      S = 0
    End If
    Print S
End Sub

End
```

the photos).

Software

The C software for this project (ATM18_IRDMS_GP2xxx, downloadable from www.elektor.com) is quite straightforward in use. Two limit values are defined, and the program monitors these values and uses the LEDs to indicate the switching points. If the LC display is connected, three values are displayed: the output of the A/D converter (ADC: xxx), the upper limit (UL: xxxx), and the lower limit (LL: xxxx) (see **Figure 8**).

You can press S1 (left button) to set lower limit to the current sensor value, or press S3 (right button) to set the upper limit to the current sensor value. If you press the middle button (S2), the upper limit and lower limit are set to the default values.

After the limit values have been set, you can move almost any desired object around in the acquisition range, and the voltage generated by the sensor will be shown on the display. If the either of the limit values is reached, the corresponding LED on the prototyping board lights up. A possible application for this arrangement would be controlling a robot so that it never gets trapped in a corner and avoids obstacles. Of course, the distance parameter values could also be adjusted dynamically by the software according to the speed of motion.

For developing your own applications, we can provide a small tip here. You can determine the distance with reasonably good accuracy by using the following simple formula:

$$\text{Distance} = \frac{0.008271 + 939.6 \times U_S}{1 - 3.398 \times U_S + 17.339 \times U_S \times Us}$$

Here *Us* is the sensor signal voltage, which ranges from 2.5 V at a distance of 20 cm to 0.45 V at a distance of 150 cm.

Naturally, this can be calculated much faster than the previously stated formulas. It can also be used in a Bascom-based solution.

If you need to make distance measurements in an application and convert them to physical units, you naturally want to use the fastest possible method, which means using a look-up table. This involves creating a table of sensor output voltages for the entire distance range and having the software read values from this table.

However, the implementation described here provides an adequate starting point for enabling a mobile object to decide which action to take, similar to the way a bat navigates with its ultrasonic localisation system. If an obstacle is looming, the motors can be stopped, and if the object keeps on coming, they can be put into reverse. That's something even a bat can't do!

Lamp control in Bascom

The Bascom program (downloadable from www.elektor.com) uses the sensor for a simple lamp control instead of displaying the measured distance to an object. The lamp in question is a desk lamp, which is controlled via all bits of Port B. One option is to use the ULN2003 driver IC on the board to drive a relay.

In use, the distance sensor is aimed at the work station. If someone approaches the desk, the lamp goes on automatically. If they leave the work station, the lamp is switched off after a delay of 100 seconds. The movements of the person working at the desk are also monitored. With normal desk work, people constantly move around by more than 3 cm. If motion is no longer observed, the person being monitored has probably fallen asleep. In this case, the desk lamp is switched off in the interest of a good office nap. However, it switches back on immediately if the boss comes by and wakes his employee.

The function Calculate_s (**Listing 1**) makes a measurement and converts the result into the distance s in centimetres. The calculation must be performed in individual steps in Bascom; writing the full expression in a single line with lots of parentheses won't work here. The voltage measurement code takes into account the voltage divider (6.8 kΩ / 4.7 kΩ) and the internal reference voltage (1.1 V). The calculated distance is also sent to the PC via a 9600-baud link. Experience shows that the accuracy of the distance measurement is relatively good, with an error of around 10%. If no object is present in the visible range, a value of zero is output. The lines for an alternative sensor connection without a voltage divider, which requires using the 5-V supply voltage as the reference voltage, have been commented out.

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References and links

[1] Contactless Distance Measurement, Elektor Electronics, April 2002

[2] www.sharpsma.com

[3] Distance Measurement using Infrared, Elektor Electronics, July/August 2002

The ATM18 project at Computer:club²

ATM18 is a joint project of Elektor and Computer:club² (*www.cczwei.de*) in collaboration with Udo Jürsz, Chief Designer of *www.microdrones.de*. The latest developments and applications of the Elektor ATM18 are presented by Computer:club² member Wolfgang Rudolph in the CC²-tv programme broadcast on the German NRW-TV channel. The IR distance sensor and ATM18-AVR board combination described here was featured in ***instalment 25*** of CC²-tv.

CC²-tv is broadcast live by NRW-TV via the cable television network in North Rhine–Westphalia and as a LiveStream programme via the Internet (*www.nrw.tv/home/cc2*). CC²-tv is also available as a podcast from *www.cczwei.de* and – a few days later – from *sevenload.de*.