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Ultrasonic ranging gets thermal correction

Ultrasonic ranging is a very useful technique but can be degraded by temperature effects. Research engineers explain some techniques to overcome these.

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THIS paper presents some aspects of the research activities on sensors for robots, developed in the Instituto de Automática Industrial (IAI) during the last years. The demand for greater precision in the measurement of distances using US techniques, makes it necessary to compensate for alterations in the sound-speed in the interposed medium due to temperature. In this paper we will describe a method for calculating this correction in order that no other external sensor be necessary. The method is based on the resonance-frequency variation of the piezoelectric elements with temperature. The accuracy reached with this correction is higher than normally would be needed in robotics applications.

The pulse-echo method for the measurement of distance is based on the determination of the flight-time, used by the wave to travel from the sensor to the object and back. To transform this time into distance it is necessary to know the propagation speed of the waves in the medium. On the other hand, this velocity depends on the environmental temperature. For instance going from 0 to 40°C and measuring an object at a distance of 50 cm, if speed variation is not compensated for an error of about 6 cm (12%) will be made.

The relation between propagation speed and temperature is:

$$v = \sqrt{\beta RT/M}$$

where β is the constant compressibility modulus, R the Raleigh constant yM the molecular mass of the gas (air).

Many authors[1-5] have introduced one external temperature sensor in order to maintain the system accuracy when the temperature changes. This requires a more complicated system and the presence of another sensor that, of course, must be conveniently close to the measuring system.

On the other hand the transducers used, both to generate as well as to detect the ultrasound waves, are commonly piezoelectric having a very marked resonancy frequency. This frequency depends on the mechanical properties of the transducer, especially on the sound velocity in the material (and therefore on its nature and compressibility),[7] although there exist other influences such as the holder or coupling used. When the temperature changes, the mechanical properties of the transducers also vary thus producing a shift in the resonance frequency of the transducer.[3]

In the system described below, the calculation of the correction is based on the measurement of the displacement of the resonance frequency of the transducer due to the change in temperature. The advantages of this system are: the temperature sensor is always conveniently close to the ultrasound sensor, because they are one and the same; the system is simplified without the additional sensor. Both will increase the reliability of the system.

System description

Intending to carry out a study of the ultrasound waves reflected by different objects in different conditions, a system was made (Fig. 1). One pulse generated periodically is amplified up to 45 V and passed to the piezoelectric transducer, acting as a transmitter/receiver, with a resonance frequency of about 220 Khz. The echo proceeding the target via the transducer is amplified and filtered by a matched amplifier (G=600). The signal goes to an instrumentation digital oscillosocope. The same pulse used to excite the transducer is passed on to the oscilloscope as a trigger signal, thus allowing for the convenient and simultaneous viewing and storage of the echo signal.

The system can take 512 samples with a resolution of eight bits. The digitalised signal is transmitted to the computer by an IEEE488 channel. The computer carries out the off-line analysis of the signal. It was intended, later on, to make a specific system, processing the data in real-time according to the algorithms and strategies defined in this stadium.

In these measurements, a sample was taken every 0.391 μs, this implies a window of 0.2 ms and about 11 samples per period were collected, which can be considered sufficient for the resolution needed.

In order to measure the influence of the temperature on the sensory system, it is put in a temperature controlled chamber, where the temperature can be adjusted with precision. In this case, a range of 0 up to 35°C was used, which

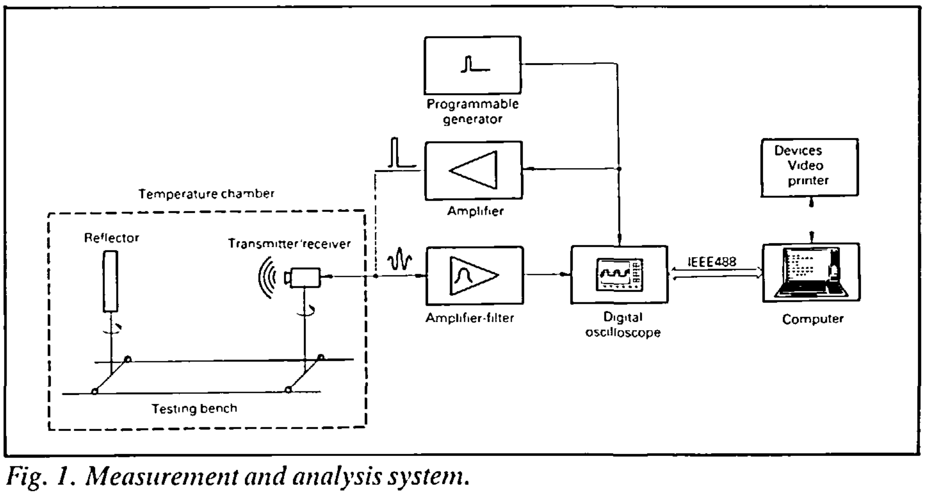


Fig. 1. Measurement and analysis system.

can be considered a wide range for this type of sensor.

Although this is an experimental system, that does not obtain the results in real-time, this problem has already been solved by other authors who digitalise the signal and therefore obtain their results in real-time.[2, 6]

Measurement method

For this correction method it is not the exact value of the temperature which is important, but rather the relation between the sound speed and the frequency of the wave.

In order to measure the sound speed a reflector has been placed at a fixed distance (50 cm) and the flight-time measured. To determine with precision the moment of the echo arrival the signal is digitalised and a tested algorithm is applied on all the samples of the echo. This algorithm fits the samples obtained on a predefined analytic function and extracts from this fitting the exact moment of the beginning of the echo. In a later paper this will be described in detail. This method of measurement eliminates the differences in the moment of detection due to the differences in the amplitude of the echo and reduces other uncertainties due to electrical or acoustical noise. Finally, the mean of three measurements was used, which gives an estimated error of 0.1 μs, which means an error of 0.015% in the speed of sound.

For the measurement of the frequency the actual digitalised signal of the echo was used. First, the envelope and the carrier signal are separated, extracting from the latter its frequency. Only the first part of the echo (to the maximum) is used in order to avoid frequency changes due to the reflector. Fig. 2a shows a typical echo, in Fig. 2b the same echo is rectified, with its calculated envelope.

Before considering whether the targets are static or almost static, if working with mobile objects, the frequency would be affected by the doppler effect The following formula gives the theoretical change in frequency caused by the speed of the target.

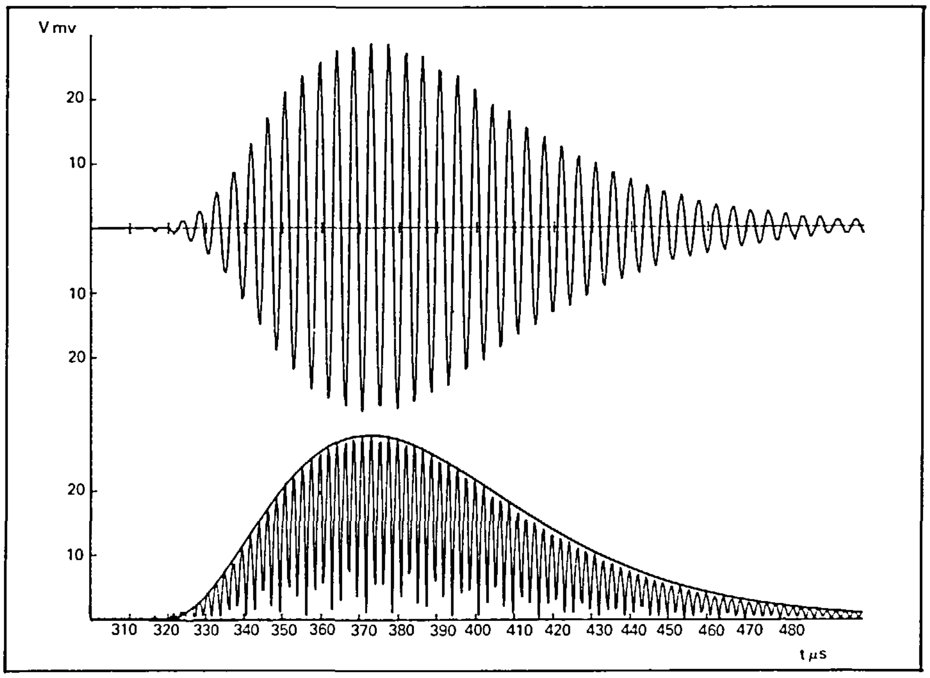


Fig. 2. Digitalised echo-signal.

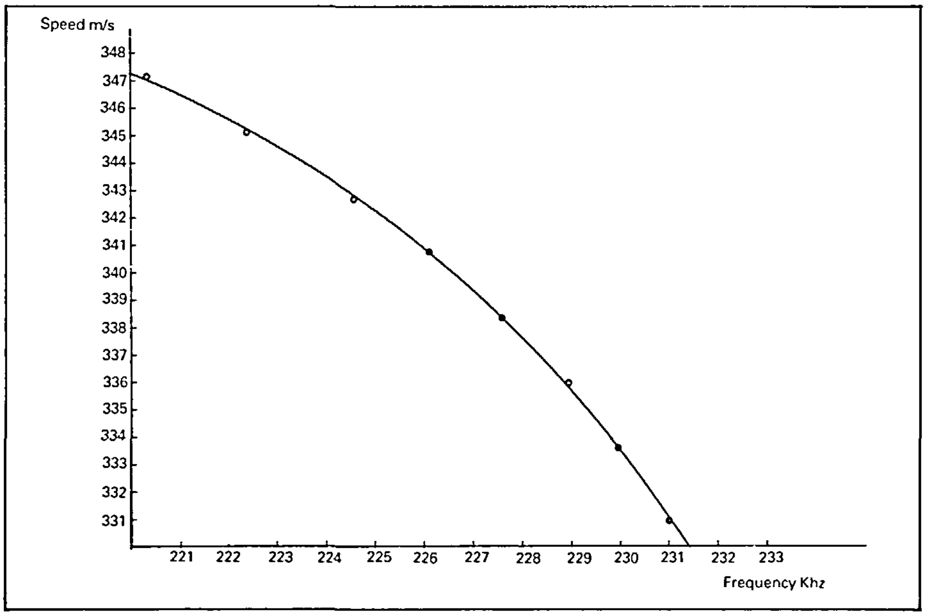
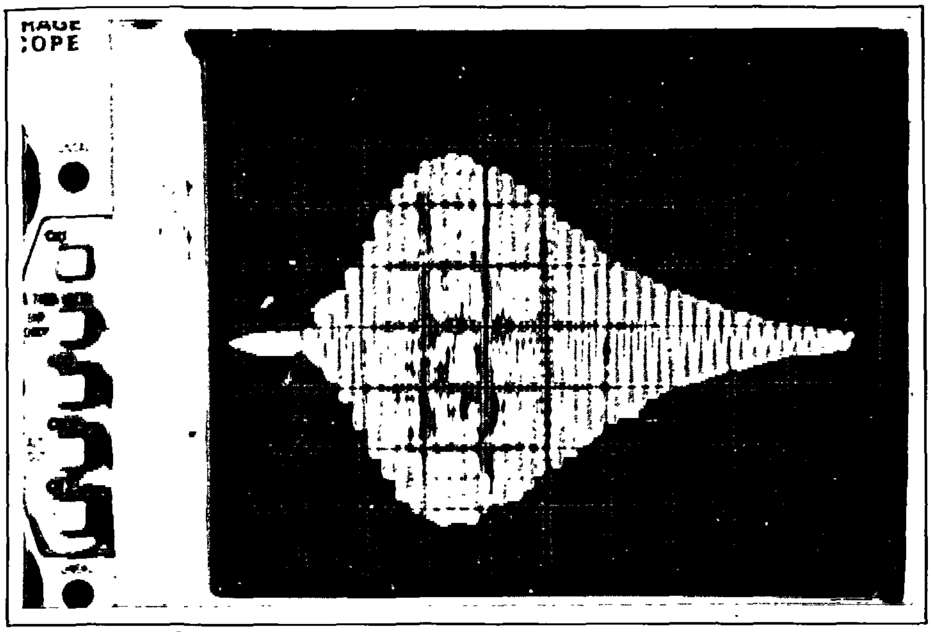


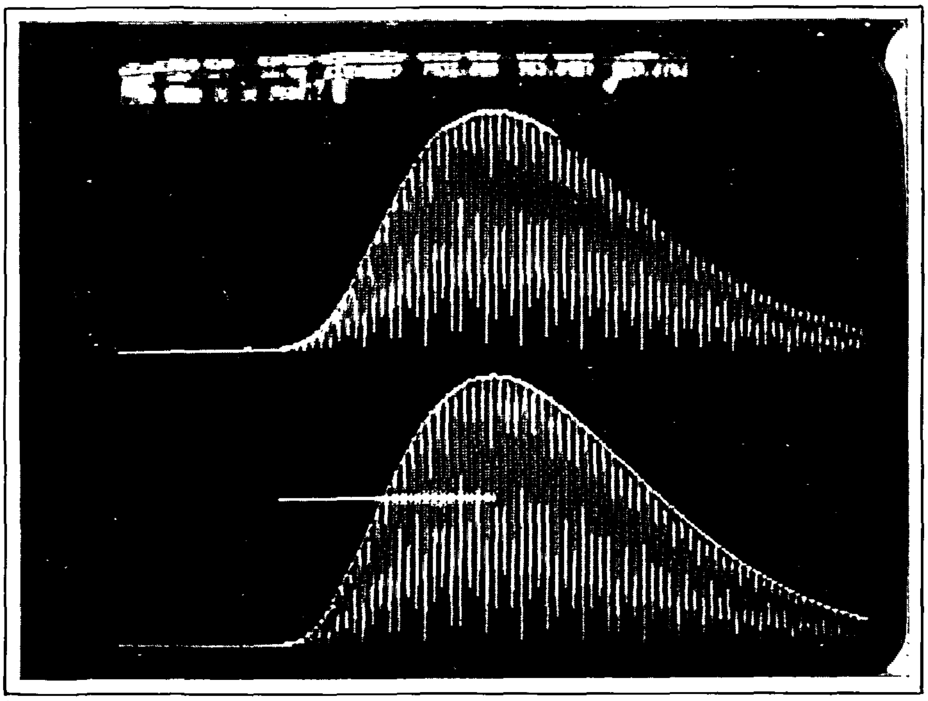
Fig. 3. Relation between the sound speed and the frequency.

$$Df = 2.f.v/u$$

Where f is the original frequency, u the sound speed in air and v the relative speed between sensor and target.[8] When it is necessary to correct for this effect it can be done in various ways: using a known fixed speed, measuring it using different techniques, or even using the same range sensor. In any case, the doppler effect does not affect the measurement of the frequency as much as it does the temperature: in the case of $v = 1$ m/s (which is a relative high speed in robotics) a change of 227 Hz occurs, and going from 0 to 35°C there is a difference of 10 Khz in the resonance frequency.



The echo signal as seen on the oscilloscope.



The echo signal analysed on the computer.

In the static experiments three measurements are used for its temperature point. The estimated error in the measurement of the frequency is 0.01%. Knowing the relation between sound speed and resonance frequency, this error implies that for a target of 50 cm after the correction there is an error of less than 0.15 mm.

Results

Fig. 3 shows the sound speed measurements against the resonance frequency at the same temperature. These change from 0 up to 35°C in steps of five degrees. Between the measured points an empirical curve is fitted according to the expression:

$$v = c.e^{af} + b$$

where a, b and c are empirical constants.

When using this correction in a system working in real-time it is better to table these values after calibration rather than use the table for the correction. The standard deviation between the measured points and the fitted curve is 0.012%, which is less than can be expected knowing the error made in the measurements of the two parameters. If greater precision is needed a lot more measurements for calculating can be used considering that temperature is a slowly changing parameter.

Conclusion

An alternative method is shown in order to correct the variation of sound speed with temperature in ultrasound range sensors without the need for an external sensor. It is shown that the method gives a precision of 0.015% in the calculation of the sound speed in a range from 0 to 35°C, although the method can be improved in order to obtain greater precision using the same techniques. □

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