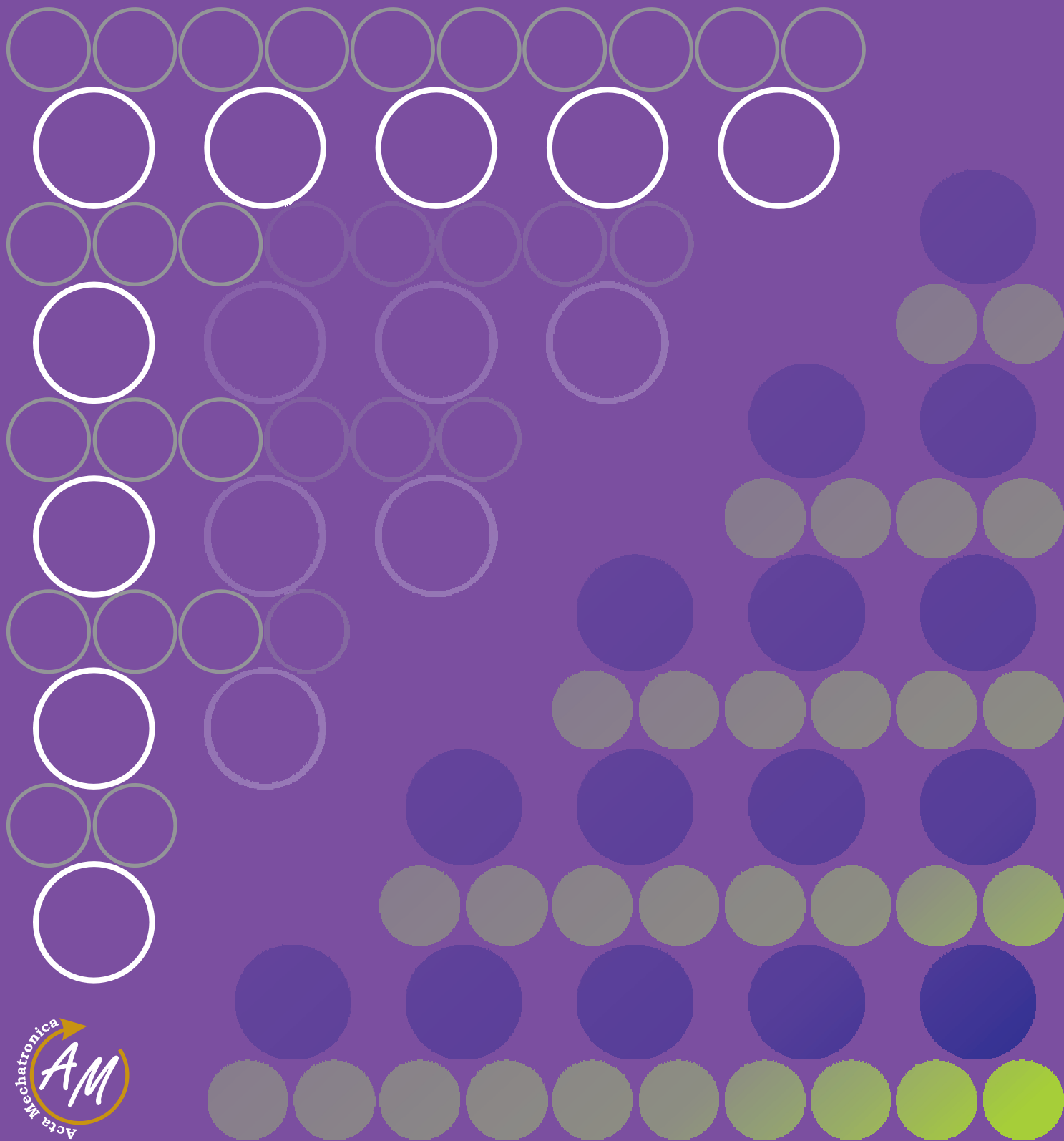


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CONDITION OF ULTRASONIC DISTANCE MEASUREMENT SYSTEM

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Abstract: There are several types of position sensors, which can be used for distance measurement. There is a need for more accurate distance sensor. Ultrasonic sensor are very popular mainly in robotics application as navigation sensor for contactless sensing of obstacles for navigation purpose. Ultrasonic distance sensor uses often time to flight principle for measurement. Some of them also uses Doppler Effect for distance measurement. The aim is to obtain uncertainty measurement for measurement chain with ultrasonic distance sensor. Uncertainty of measurement quantifies how it is possible to believe to measurement results.

1 Introduction

These sensors are independent on material type and surface colour and also independent on optical condition. Ultrasonic distance sensor uses often time to flight principle for measurement (Figure 1). Some of them also uses Doppler Effect for distance measurement. Ultrasonic sensor are very popular mainly in robotics application as navigation sensor for contactless sensing of obstacles for navigation purpose. This sensor can have problem with distance sensing in case of object made from vibration absorbent material.

Ultrasonic sensors can be made in two arrangement as system with ultrasonic transmitter and receiver and also there are group of ultrasonic sensors with only one ultrasonic transducer, which is used as transmitter and also as receiver (Figure 2). Ultrasonic sensor can be used also for checking of quality products, discontinuities in material and also as sensor for detection of technology processes (material and tools position), material thickness (corrosion and defects) etc. Ultrasonic is also usable for water level detection.

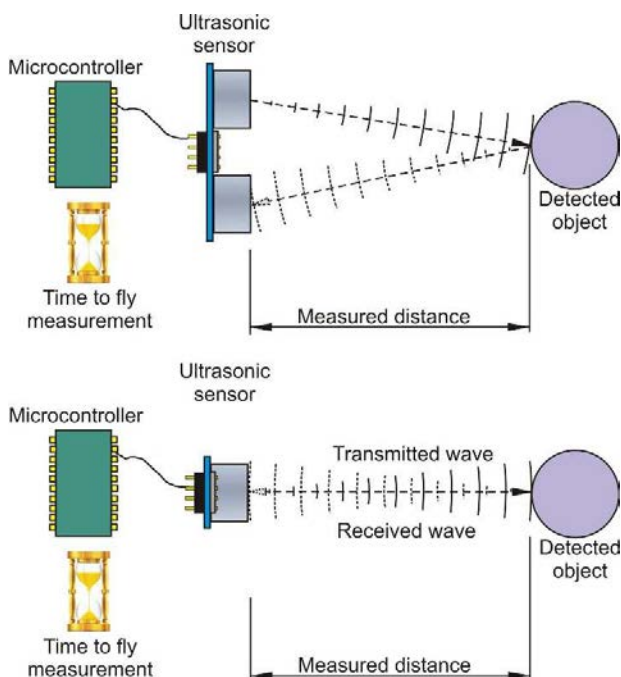


Figure 1 Ultrasonic distance sensor principles

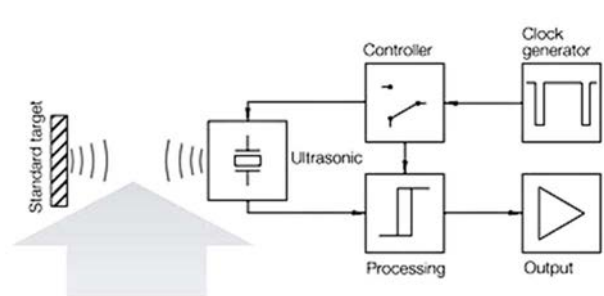


Figure 2 Ultrasonic distance sensor arrangement with one ultrasonic transducer

Ultrasonic sensor are able to measure distance in range from 30 mm up to 10 m depending on sensor producer. Sensors are available as switching output type or analogue output type.

Ultrasonic wave sound uses frequency in range from 20 kHz up to 50 MHz depending on application. After applying of voltage pulse on ultrasonic transmitter, it generates sound wave which pass through the medium (air, metal, water etc.). If any object occurs, then sound wave echo reflects back to receiver. Half of measured time of

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received echo represent the object distance. The velocity of sound in air is approximately 340m/s, but it depends on many factors as medium density, temperature, humidity and ambient pressure [1-3].

2 Testing of the ultrasonic distance sensor

Tested sensor has analogue output and uses the sound with frequency 300 kHz. Measurement range interval is from 100 to 1000 mm. Measurement has been realised at temperature 20°C and relative humidity 65%. The aim is to obtain uncertainty measurement for measurement chain with ultrasonic distance sensor for solid and soft obstacle material (Figure 3). Gauge length blocks have been used for testing of the sensor (Figure 4).

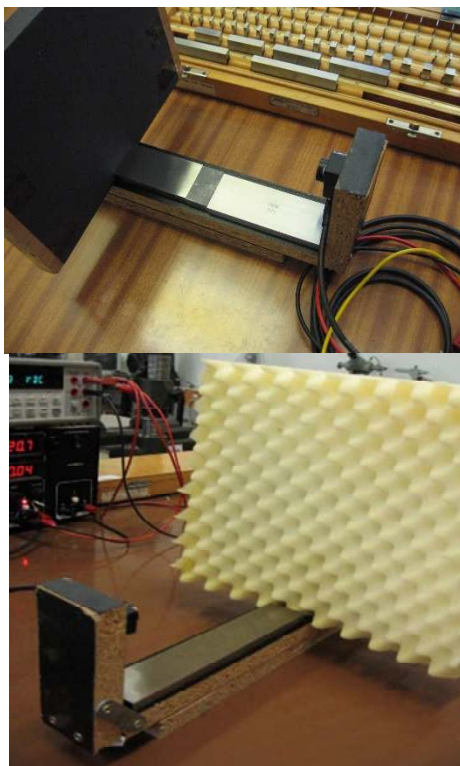


Figure 3 Testing of the ultrasonic distance sensor with gauge length blocks



Figure 4 Gauge length blocks

Transformation characteristic (Figure 5) has been measured for both material. There is only small difference between them, because of the non-planar surface of obstacle material. As it is shown on Figure 5, there is a dead zone up to 120 mm distance from obstacle. After change of axis, it is possible to obtain the calibration characteristic and after approximation of experimental data, the math model is obtained on Figure 6. Math model can be used for obtaining of the measured length.

Every measurement result has to be noted with uncertainty of measurement. Uncertainty of measurement quantifies how it is possible to believe to measurement results. In accordance with rules for identification of uncertainty, there is a possibility to obtain standard uncertainty of measurement obtained by the method A and method B. Method A means that standard uncertainty can be quantifies as standard deviation, but it is possible to do it only in case when there is a set of minimum of 10 measurement obtained at the same conditions. Method B means that standard uncertainty can be obtained from datasheet from sensor manufacturer. In this case there is only data which not fulfil condition for reporting of standard uncertainty obtained by the method A. Consequently, in next steps only standard uncertainty by the method B will be reported.

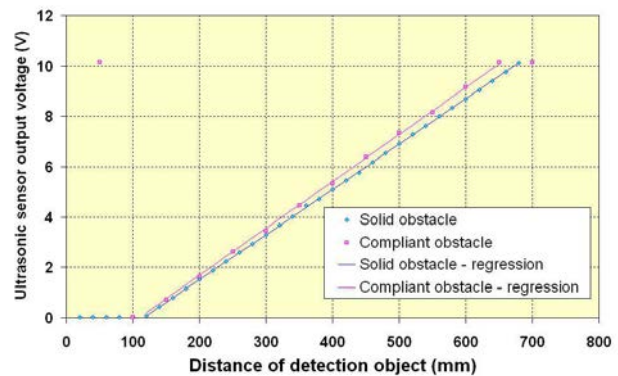


Figure 5 Transformation characteristic for ultrasonic distance sensor

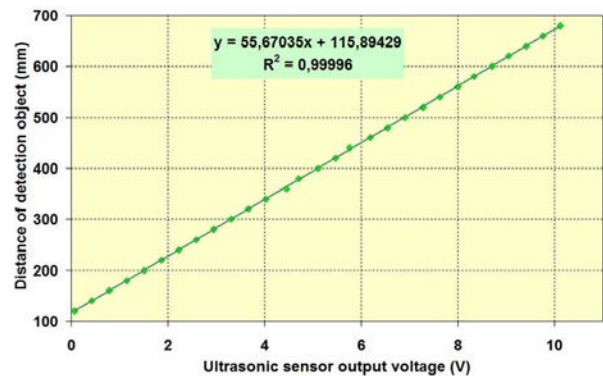


Figure 6 Calibration characteristic for ultrasonic distance sensor

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3 Uncertainty of measurement

Next uncertainty is reported for overall measurement chain, which consist of digital multimeter and gauge length. Obtained experimental data have been fitted with linear model of measurement:

$$y = b_0 + b_1 \cdot x \quad (1)$$

Where x is voltage output from ultrasonic sensor and y is measured distance. Coefficients b_0 and b_1 is shown on figure 6 from linear approximation of measured data. From practical viewpoint the measured quantities have own uncertainty of measurement and also coefficients b_0 and b_1 is will have own uncertainty defined with next equations:

$$u^2_{(b_1)} = \frac{n}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \cdot \sigma^2;$$

$$u^2_{(b_0)} = \frac{\sum_{i=1}^n x_i^2}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \cdot \sigma^2 \quad (2)$$

There is a possibility that between coefficients is any functional relation. Covariance between coefficients will express it:

$$u_{b_0, b_1} = \text{cov}(b_0, b_1) = \frac{-\sum_{i=1}^n x_i}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \cdot \sigma^2 \quad (3)$$

Where σ can be expressed with variance:

$$\sigma^2_{MSE} = \frac{1}{n-2} \sum_{i=1}^n [w_i - (b_1 \cdot x_i + b_0)] \quad (4)$$

Standard uncertainty for measured distance can be obtained as:

$$u_y = \sum_{j=0}^p x^{2-j} \cdot u_{b_j} + \left(\sum_{j=1}^p j \cdot x^{j-1} \cdot b_j \right)^2 \cdot u_x^2 + 2 \cdot \sum_{j=0}^{p-1} \sum_{k=j+1}^p x^j x^k u_{b_j, b_k} \quad (5)$$

After simplification equation can be expressed as:

$$u_y = (u_{b_0}^2 + x^2 \cdot u_{b_1}^2) + b_1 \cdot u_x^2 + 2(x \cdot u_{b_0, b_1}) \quad (6)$$

Using the previous equation, uncertainty of measured distance can be obtained. Results are shown on Figure 7.

Maximum uncertainty is 0.91 mm. This uncertainty depends on many factors as environmental condition and also on other parts of measurement chain. One possible way is to determine influence of all significant factors and determine math model of sensor.

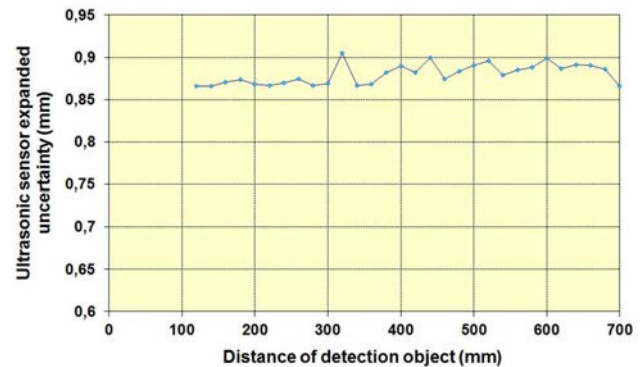


Figure 7 Standard uncertainty for distance measured by ultrasonic sensor

4 Conclusion

Ultrasonic sensors are very popular sensors in automotive industry and also in robotic application. Backup parking sensors mounted in almost every car are also ultrasonic sensors. There is only problem if it is raining or snowing. Ultrasonic sensor are frequently used in robotic application as collision detection sensor and mapping sensor for navigation of mobile robot in unknown environment. These application do not need the precise measurement. Ultrasonic measurements have a problem with many factors as temperature, humidity, ambient pressure etc. [4-31].

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