Acta Mechatronica - International Scientific Journal about Mechatronics
Volume: 4 2019 Issue: 2 Pages: 1-5 ISSN 2453-7306

CONDITION OF ULTRASONIC DISTANCE MEASUREMENT SYSTEM
Tatiana Kelemenová; Eduard Jakubkovič

doi:10.22306/am.v4i2.47

CONDITION OF ULTRASONIC DISTANCE MEASUREMENT SYSTEM

Tatiana Kelemenová
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, EU,
tatiana.kelemenova@tuke.sk (corresponding author)
Eduard Jakubkovič
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, EU,
eduard.jakubkovic@tuke.sk

Keywords: ultrasonic sensor, measurement, calibration, uncertainty, gauge

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.

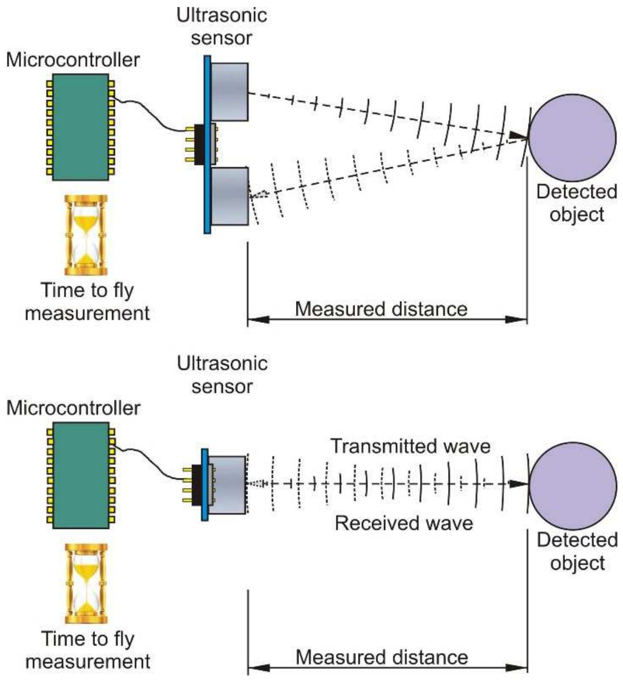

Figure 1 Ultrasonic distance sensor principles

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.

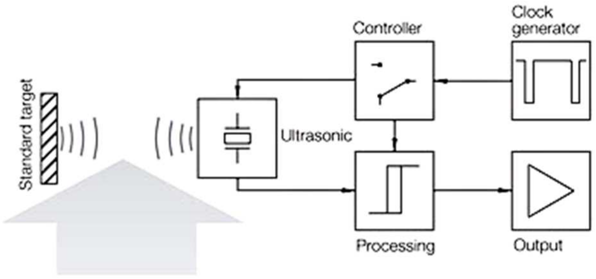

Figure 2 Ultrasonic distance sensor arrangement with one ultrasonic transducer

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 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).

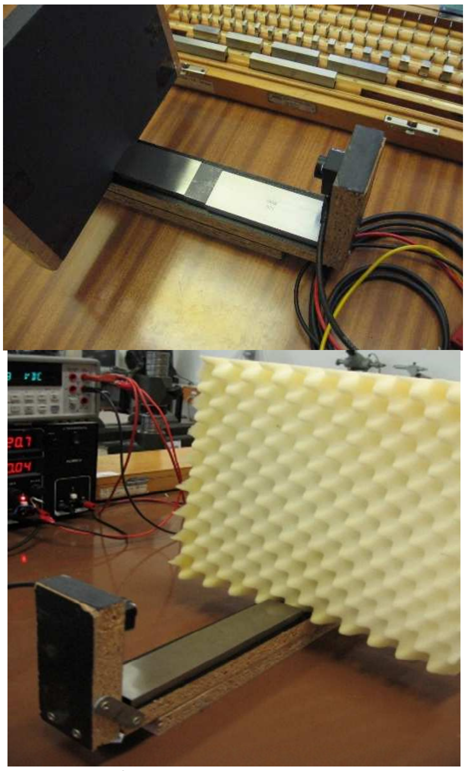

Figure 3 Testing of the ultrasonic distance sensor with gauge length blocks

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.

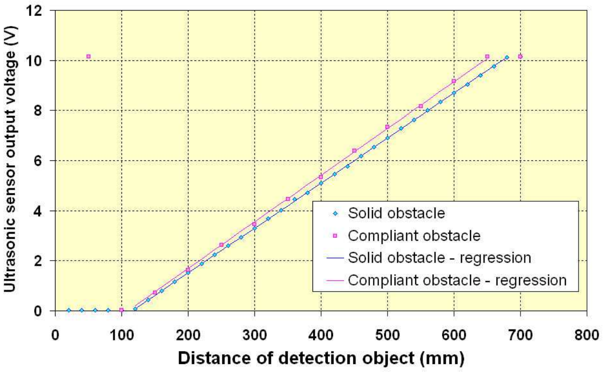

Figure 5 Transformation characteristic for ultrasonic distance sensor

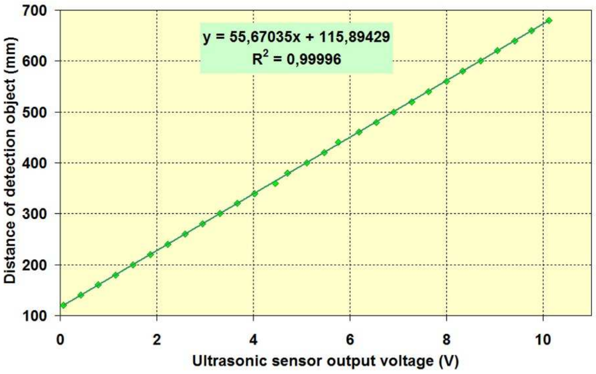

Figure 6 Calibration characteristic for ultrasonic distance sensor

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:

$$y = b_0 + b_1 \cdot x \tag{1}$$

Where x is voltage output from ultrasonic sensor and *y* is measured distance. Coefficients *b₀* and *b₁* 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 *b₀* and *b₁* is will have own uncertainty defined with next equations:

$$u^2{}_{(b1)} = \frac{n}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \cdot \sigma^2;$$

$$u^2{}_{(b0)} = \frac{\sum_{i=1}^{n} x_i^2}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \cdot \sigma^2 \tag{2}$$

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

$$u_{b0,b1} = \operatorname{cov}(b0, b1) = \frac{-\sum_{i=1}^{n} x_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \cdot \sigma^2 \tag{3}$$

Where σ can be expressed with variance:

$$\sigma_{MSE}^2 = \frac{1}{n-2}\sum_{i=1}^{n}\left[w_i - \left(b_1 \cdot x_i + b_0\right)\right] \tag{4}$$

Standard uncertainty for measured distance can be obtained as:

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

After simplification equation can be expressed as:

$$u_y = (u_{b0}^2 + x^2 \cdot u_{b1}^2) + b_1 \cdot u_x^2 + 2\left(x \cdot u_{b0,b1}\right) \tag{6}$$

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.

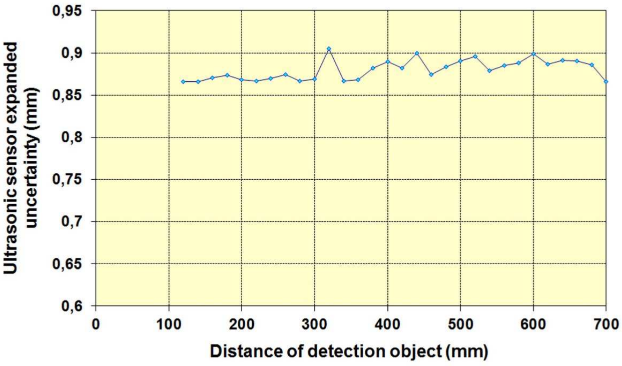

Figure 7 Standard uncertainty for distance measured by ultrasonic sensor

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].

Acknowledgement

The work has been accomplished under the research project APVV-15-0149, VEGA 1/0224/18, KEGA 006STU-4/2018 financed by the Slovak Ministry of Education.

References

[1] PALLÀS-ARENY, R., WEBSTER., J.: *Sensors and Signal Conditioning*, 2nd ed., Toronto, Ontario: John Wiley & Sons, 2001.

[2] CARR, J. J.: *Sensors and Circuits*, Upper Saddle River, NJ: PTR Prentice-Hall, Inc., 1993.

[3] EA-4/02 *Expression of the Uncertainty of Measurement in Calibration*, European co-operation Accreditation Publication Reference, December, 1999.

[4] VITKO, A., JURIŠICA, L., KĽÚČIK, M., MURÁR, R., DUCHOŇ, F.: Sensor Integration and Context Detection in Mechatronic Systems, *Mechatronika* 2008: Proceedings of 11th International Conference on Mechatronics. Slovakia, Trenčianske Teplice, June 4-

6, 2008, Trenčín: Trenčianska univerzita Alexandra Dubčeka v Trenčíne, pp. 49-53, 2008.

[5] KONIAR, D., HARGAŠ, L., HRIANKA, M.: *Application of standard DICOM in LabVIEW*, Proceeding of 7th conference Trends in Biomedical Engineering, Kladno 11.–13. September 2007.

[6] VITKO, A., JURIŠICA, L., KĽÚČIK, M., MURÁR, R., DUCHOŇ, F.: Embedding Intelligence Into a Mobile Robot, *AT&P Journal Plus*, No. 1: Mobile robotic systems, pp. 42-44, 2008.

[7] BOŽEK, P.: Robot path optimization for spot welding applications in automotive industry, *Tehnicki vjesnik / Technical Gazette*, Vol. 20, No. 5, pp. 913-917, 2013.

[8] DUCHOŇ, F., BABINEC, A., KAJAN, M., BEŇO, P., FLOREK, M., FICO, T., JURIŠICA, L.: Path planning with modified a star algorithm for a mobile robot, *Procedia Engineering*, Vol. 96, pp. 59-69, 2014.

[9] PÁSZTÓ, P., HUBINSKÝ, P.: Mobile robot navigation based on circle recognition, *Journal of Electrical Engineering*, Vol. 64, No. 2, pp. 84-91, 2013.

[10] ABRAMOV, I. V., NIKITIN, Y. R., ABRAMOV, A. I., SOSNOVICH, E. V., BOŽEK, P.: Control and Diagnostic Model of Brushless DC Motor, *Journal of Electrical Engineering*. Vol. 65, No. 5, pp. 277-282, 2014.

[11] KONIAR, D., HARGAŠ, L., ŠTOFAN, S.: Segmentation of Motion Regions for Biomechanical Systems, *Procedia Engineering*, Vol. 48, pp. 304-311, 2012.

[12] FATIKOW, S., REMBOLD, U.: *Microsystem Technology and Microrobotics*, Berlin Heidelberg, Springer-Verlag, 1997.

[13] CHUDÝ, V., PALENČÁR, R., KUREKOVÁ, E., HALAJ, M.: *Measurement of technical quantities*, Edition of STU, 1999. (Original in Slovak)

[14] JCGM 100 – *Evaluation of measurement data – Guide to the expression of uncertainty in measurement* (ISO/IEC Guide 98-3), September 2008, Online, Available: http://www.iso.org/sites/JCGM/GUM-JCGM100.htm; http://www.bipm.org/en/publications/guides/gum_print.html

[15] JCGM 104 – *Evaluation of measurement data – An introduction to the "Guide to the expression of uncertainty in measurement"* (ISO/IEC Guide 98-1), July 2009, Online, Available: http://www.bipm.org/en/publications/guides/gum_print.html

[16] JCGM 200 - *International vocabulary of metrology – Basic and general concepts and associated terms (VIM) 3rd edition* (2008 version with minor corrections). © JCGM 2012, Online, Available: http://www.iso.org/sites/JCGM/VIM-JCGM200.htm

[17] KREITH, F.: *The CRC Handbook of Mechanical Engineering*, CRC PRESS, New York, 2004.

[18] MELOUN, M., MILITKÝ, J.: *Statistical analysis of experimental data*, Praha, Academia, 2004. (Original in Czech)

[19] EA-4/02 *Expression of the Uncertainty of Measurement in Calibration*, European co-operation Accreditation Publication Reference, December 1999.

[20] MSA 104/97 *Expression of the Uncertainty of Measurement in Calibration*, (EAL-R2) - Expression of the Uncertainty of Measurement in Calibration, Slovenská národná akreditačná služba, SNAS BRATISLAVA, December 1997

[21] MSA 104/D1-98 *Appendix 1 for MSA 104-97 Expressing of measurement uncertainties in Calibration* (EAL-R2-S1), (EA-4/02-S1) Supplement 1 to EAL-R2 Expression of the uncertainty of measurement in calibration, Slovak national accreditation service, SNAS BRATISLAVA, October 1998. (Original in Slovak)

[22] MSA-L/11 *Guidelines on the expression of uncertainty in quantitative testing (In Slovak)* (EA - 4/16: 2003). Guidelines on the expression of uncertainty in quantitative testing. Slovak national accreditation service, SNAS BRATISLAVA, August 2009.

[23] MSA–L/12 *Expression of the uncertainty of measurement in calibration* (EA-4/02) - Expression of the uncertainty of measurement in calibration, Slovak national accreditation service, SNAS BRATISLAVA, November 2010. (Original in Slovak)

[24] TPM 0050-92 *Etalons. Expressing of errors and uncertainties*, Metrological Technical Directive. Slovak Metrological Institute. Bratislava, 1992. (Original in Slovak)

[25] TPM 0051-93 *Expressing of uncertainties in measurement*, Metrological Technical Directive. Slovak Metrological Institute. Bratislava, 1993. (Original in Slovak)

[26] WIMMER, G., PALENČÁR, R., WITKOVSKÝ, V.: *Stochastic models of measurement*, Graphic Studio Ing. Peter Juriga, Ľ. Fullu 13, 841 05 Bratislava, 2001. (Original in Slovak)

[27] PALENCAR, R., SOPKULIAK, P., PALENCAR, J., ĎURIŠ, S., SUROVIAK, E., HALAJ, M.: Application of Monte Carlo Method for Evaluation of Uncertainties of ITS-90 by Standard Platinum Resistance Thermometer, *Measurement Science Review*, Vol. 17, No. 3, pp. 108-116, 2017.

[28] SOPKULIAK, P., PALENCAR, R., PALENCAR, J., SUROVIAK, E., MARKOVIČ, J.: Evaluation of Uncertainties of ITS-90 by Monte Carlo Method, Conference: 6th *Computer Science On-Line Conference* (CSOC) Location: Zlin, CZECH REPUBLIC Date: APR, 2017. CSOC2017, Vol. 2,

Book Series: Advances in Intelligent Systems and Computing, Vol. 574, pp. 46-56, 2017.

[29] SPANIKOVA, G., SPANIK, P., FRIVALDSKY, M., PAVELEK, M., BASSETTO, F., VINDIGNI, V.: Electric model of liver tissue for investigation of electrosurgical impacts, *Electrical Engineering*, Vol. 99, No. 4, pp. 1185–1194, 2017. doi:10.1007/s00202-017-0625-0

[30] KURIC, I., BULEJ, V., SAGA, M., POKORNÝ, P.: Development of simulation software for mobile robot path planning within multilayer map system based on metric and topological maps, *International Journal of Advanced Robotic Systems,* Vol. 14, No. 6, pp. 1-14, 2017. doi:10.1177/1729881417743029

[31] HARGAS, L., KONIAR, D., SIMONOVA, A., HRIANKA, M., LONCOVA, Z.: Novel Machine Vision Tools Applied in Biomechatronic Tasks, *Procedia Engineering,* Vol. 96, pp. 148-156, 2014.

Review process

Single-blind peer review process.