

A/D Conversion Error Propagation in Distance Measurement with a Sonar System based on Piezopolymer Sensors

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Abstract - The paper deals with the investigation on the propagation of the A/D conversion error during the distance measurement with an ultrasonic sensor aimed to emulate the behaviour of the bat bio-sonar.

In previous experiments the echo signals were processed with a 8 bit DSP and the target distance of 27 cm was evaluated with an accuracy of $\lambda/50$, but until now the nature of the measurement error was not verified.

The signal reconstruction algorithm should employ an inverse transfer characteristic with respect to that of the sensor. In the proposed application the propagation error is evaluated at different distances ranging from 27 cm to 200 cm (one-path way), by considering an ideal signal reconstruction block, which however processes the global conversion error. At the minimum distance the results are in good agreements with those one obtained in the experiments.

Keywords - A/D conversion error propagation, sonar system, distance measurement.

I. INTRODUCTION

A digital system for ranging in air with piezopolymer ultrasonic sensors was presented in [1]. The system was based on PVDF (Poly-Vinylidene-Fluoride) curved transducers resonating at about 63.5 kHz and the ranging was achieved by evaluating the transit time of an ultrasonic echo signal with digital phase measurement techniques.

The phase measurement was performed by processing the in-quadrature and in-phase components of the echo signals.

The received analog signal was first sampled, than converted in the digital one, and finally sent to a 8 bit DSP. The time of flight was calculated according to the following procedure. A coarse evaluation of the range distance was obtained with a threshold method, afterwards a fine calculation was obtained by averaging the in-quadrature and in-phase components, and by evaluating the phase measurements. The distance measurement accuracy was better than $\lambda/50$ in a range of 27 cm (54 cm two way path, $\lambda_{\text{air}} = 5.4$ mm at 63.5 kHz).

Such a typical digital measurement system includes sensor, signal conditioner, A/D converter and signal reconstruction blocks [2]. The measurement resolution of the distance is not only determined by the resolution of the A/D converter, but it will also be influenced by the characteristic of the reconstruction algorithm. In our application the influence of secondary variables was not considered.

In this work we are interested in evaluating the influence of the propagation of the global A/D conversion error during similar measurements, also at different distance of the target.

II. MEASUREMENT SYSTEM MODEL

Our primary interest is that of investigating the possibility to use a PVDF sensor to emulate the bio-sonar of bats. The target distance could be much more than 27 cm (54 cm two way path) and could

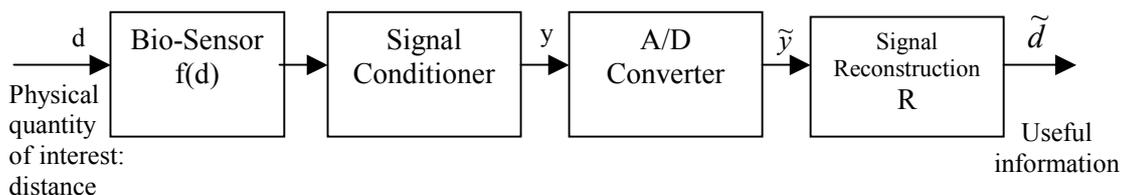


Fig. 1 Distance measurement system with a PVDF ultrasonic sensor.

reach, in practical applications, 200 cm (400 cm two way path). Although the biological approach is based on neural networks (in this context we are working on an analog neural system), we investigate the possible advantages offered by a digital system.

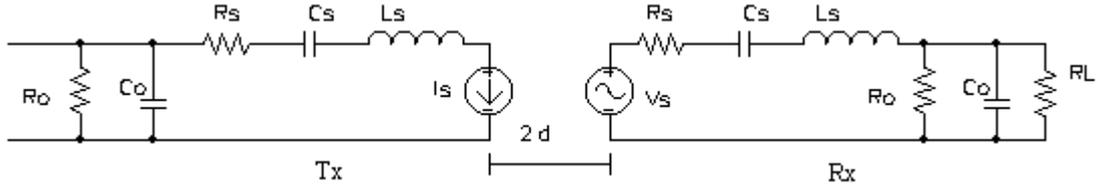


Fig. 2 Electrical model of the sonar system based on piezopolymer sensor. d is the target distance (one-path way). T_x and R_x are the transmitter and receiver electrical model respectively, in which R_s , C_s , L_s and C_o , R_o are the parameters of the resonant and static arms.

In our application the measurement system, shown in Fig. 1, includes a PVDF ultrasonic sensor that converts acoustical waves carrying the measured information (the target distance d), in an electrical signal through a transfer characteristic $f(d)$. It also includes a conditioner block, an A/D converter, and a functional block which, according to a proper algorithm, reconstructs the original signal, that is the distance d . Ideally such block should implement the inverse of the function $f(d)$ [3].

The behaviour of the $f(d)$ block is better explained by observing Fig. 2. It shows the electrical model of the sonar system in order to measure the target distance in air, d , by using a piezopolymer sensor. The transmitter, T_x , properly excited from a current I_s (analogous of piezo-film velocity), sends an

ultrasonic wave toward the target positioned at the distance d . The ultrasonic echo wave is viewed by the receiver like a voltage V_s (analogous of the force exerted by the acoustic wave on to the piezo-film) which contains information on the distance and other fine characteristics of the target.

Considering V_s only dependent by the distance, the absolute value of the ratio V_s/I_s is a function of the distance d , that is $f(d)$.

III. SIMULATION RESULTS

A/D conversion error is an important and delicate step in the mimes of the bio-sonar to calculate the target distance, and its propagation deserves particular attention to avoid resolution losses.

In Fig. 1 the signal conditioning block makes the output voltage of the ultrasonic sensor compatible with the input characteristics of the A/D converter used for quantizing the signal. In simulation we have considered a $\Sigma\Delta$ A/D converter whose behavioural model [4] includes the gain, amplitude

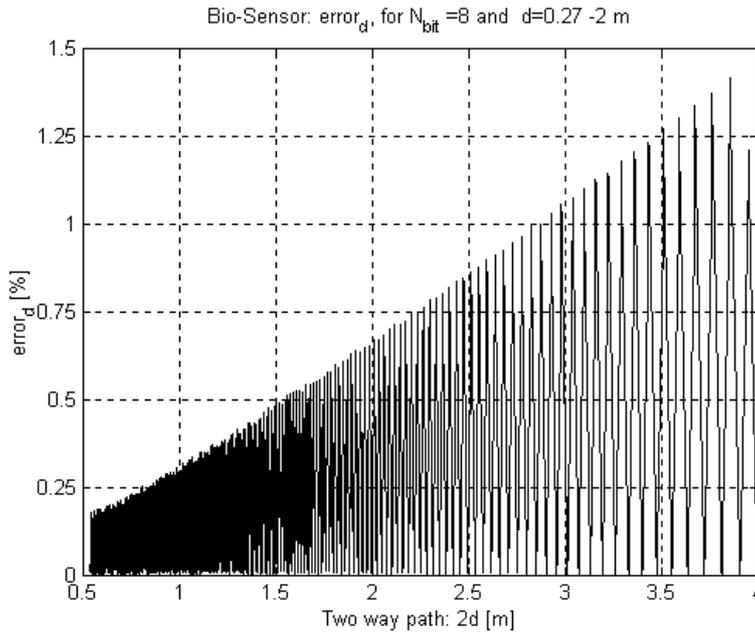


Fig. 3 Relative error estimated on the target distance measurement d ranging from 27 cm to 2 m for an 8 bit resolution.

compression, distortion and quantization errors, according to the parameters adopted in [5].

good agreement with those one obtained in previous experiment.

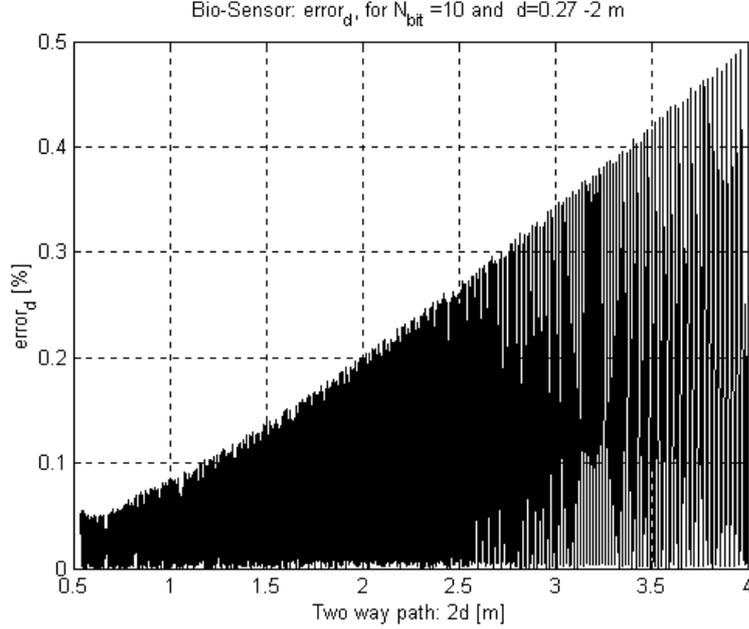


Fig. 4 Relative error estimated on the target distance measurement d ranging from 27 cm to 2 m for an 10 bit resolution.

Indicating with \tilde{y} the output of the A/D converter, the measured distance is equal to:

$$\tilde{d} = R(\tilde{y}).$$

Thus, despite the ideality of its transfer characteristic, the R block processes the A/D errors giving the following measure error:

$$\varepsilon_d = |d - \tilde{d}|.$$

According to the electro-mechanical parameters used in experiment, the sonar system is characterized by the following [6]:

$$\frac{\bar{V}_s}{\bar{I}_s} = \frac{25.49}{d} e^{-0.08d} e^{j[\arctg(2326d) - 2326d - 65.8]}.$$

Assuming an unitary value of I_s , one achieve:

$$f(d) = \left| \bar{V}_s \right| = \left| \frac{25.49}{d} e^{-0.08d} e^{j[\arctg(2326d) - 2326d - 65.8]} \right|.$$

Using Matlab program we have simulated the whole system shown in Fig. 1 and we have verified that our results, at a target distance of 27 cm, are in

The error is due to the reconstruction process during the propagation of the ADC global error.

Figs 3 and 4 show the error for various target distances ranging from about 27 to 200 cm, by using respectively an 8 and 10 bit resolution. Increasing the ADC resolution the plots loss in clarity so we report in Fig. 5 only the maximum error for 12, 14, 16 bit, respectively.

According to experimental results the 8 bit ADC error increases with the target distance and reach the value of about 5.2 cm for $d=200$ cm.

IV. CONCLUSIONS

In this article we have analyzed the influence of the global error propagation during a digital measure of the target distance with a sonar system based on piezopolymer sensor.

Obviously the mimesis of the biological approach is attracting because the use of the analog neural network allows us to calculate not only the target distance but it also gives us detailed information on the velocity, dimensions, azimuth, and many other fine characteristics of the target.

However, the simulation results obtained with a 16 bit ADC have demonstrated that, at least for distance measurement, the digital approach keeps its inherent robustness.

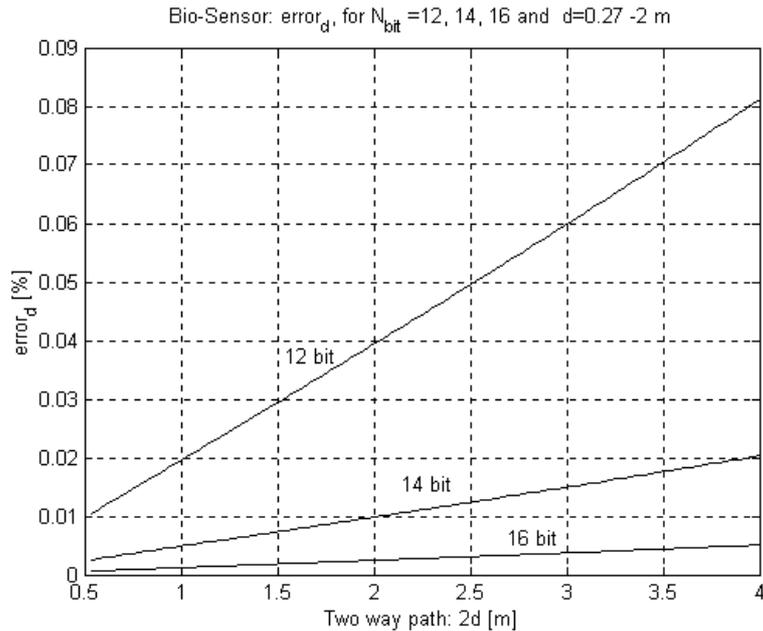


Fig. 5 Maximum relative error estimated on the target distance measurement d ranging from 27 cm to 2 m for 12, 14, 16 bit respectively.

REFERENCES

- [1] *A.S. Fiorillo*, "Ultrasound transducer with digitally synthesised wide-band for application in air", Proc. of the Int. Workshop on ADC Modelling, IMEKO'96, Smolenice Castle, Slovak Republic, pp. 226-231.
- [2] *R.Z. Morawski*, "Unified approach to measurand reconstruction," IEEE Trans. on Instrum. and Meas., vol. 43, No. 2, April 1994, pp. 226-231.
- [3] *S.Y.C. Catunda, J.-F. Naviner, D.S. Deep, R.C.S. Freire*, "Quantization effects in the resolution of the measurand in a measurement system," Symposium on Circuits and Systems, 2000. 42nd Midwest, pp. 700-704.
- [4] *A. Baccigalupi, P. Daponte, M. D'Apuzzo*, "An improved error model of data acquisition systems", IEEE Trans. on Instrum. and Meas., vol. 43, No. 2, April 1994, pp. 220-225.
- [5] *P. Arpaia, P. Daponte, F. Maccaro and S. Rapuano*, "Characterisation and modelling of the ADC Jitter", XVI IMEKO World Congress, Vienna, Austria Sept. 2000, pp. 27-31.
- [6] *A. S. Fiorillo, M. Longo*, "Modelisation and analysis of an ultrasonic system based on PVDF piezopolymers", Proc. of the AISEM-II Conf. on Sensors and Microsystems, A. D'Amico Ed., World Scientific Publ. Singapore, 1997, pp. 326-330.