



AMPLITUDE AND PHASE SHIFT CORRECTION OF THE SIGNAL DERIVATIVE BASED ON THE CORRECTION COEFFICIENTS TABLE

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Abstract – The article presents a method for correcting the derivative of a measurement signal, where the measurement error results from the signal being processed by the measurement system, altering its amplitude and phase shift. The measured values are modified using a correction coefficient that depends on the increment between successive signal values. The coefficient can be stored in the memory of a microprocessor-based sensor or another DSP system. The correction coefficient values, stored in a lookup table, are determined in advance through laboratory testing by comparing the response of a reference signal with that of the measured signal. Sample correction results are shown for a sinusoidal signal, where the phase shift is -10° , and the amplitude is 1.2 times greater than that of the reference signal. After applying the correction, the median relative error decreased from approximately -18% to negligibly small values.

Key words – data correction, error correction, measuring signal correction, phase shift

INTRODUCTION

Measurement data correction is the process of improving measurement results so that they are as accurate as possible. Measurement as such is never perfect, and its results can be affected by both systematic and random errors [1]. Data correction allows these errors to be identified and eliminated or compensated for. This leads to a more objective picture of the phenomenon under study [2-11]. First, the correction covers systematic errors that recur under specific conditions and have a known cause, e.g., under the influence of temperature, atmospheric pressure, or imperfections in signal processing by the measuring system. In the second stage, random errors that occur randomly and are difficult to predict can also be taken into account. Statistical analysis of measurement data, e.g., determining the mean value, standard deviation, or using smoothing filters, helps to minimize their impact on the final result. Data correction may

also include comparing results with reference values, e.g., with reference test results, and using various types of algorithms. In modern measurement systems, correction is often automated, and measurement sensors are equipped with microprocessors that perform correction in real time [12-15]. Correction makes data more reliable and analysis results more accurate. Correction can be based on physical models, statistics, calibration using reference values, and correction algorithms, e.g., Kalman filter, adaptive filtering, predictive algorithms.

The article presents a new correction algorithm based on comparing the reference signal and measurement values, which can be used in automatic correction systems and DSP systems.

1 IDEA

The correction algorithm is based on examining the difference between successive increments of the reference and measurement signals, assuming that the measurement signal error is a systematic error that may result from various causes, e.g. imperfections in the design and processing of the measurement transducer, or imperfections in signal processing by the entire measurement system. From the point of view of the algorithm, the cause of the errors is not important, only the final effect in the form of the difference between the reference and measurement signals matters. For this reason, the algorithm can be used to correct systematic errors of various origins. A sinusoidal signal was adopted as the reference signal, as a typical reference signal containing a wide spectrum of increments of values depending on the signal sampling time.

2 CORRECTION COEFFICIENT AND CORRECTION ALGORITHM

The reference signal \mathbf{X} and the corresponding measurement signal \mathbf{Y} take the form of sequences containing successive measurement values sampled at sampling intervals dt :

$$\mathbf{X} = [x_1, x_2, \dots, x_n] \quad (1)$$

$$\mathbf{Y} = [y_1, y_2, \dots, y_n] \quad (2)$$

Signal differences are stored as strings:

$$d\mathbf{X} = [dx_1, dx_2, \dots, dx_{n-1}] \quad (3)$$

$$d\mathbf{Y} = [dy_1, dy_2, \dots, dy_{n-1}] \quad (4)$$

The values of differential quotients result from Newton's definition of a derivative at points separated by dt .

The correction coefficient η is defined as determined by the increments of the reference and measurement signals at point i :

$$\eta_i = \frac{dx_i}{dy_i} \quad (5)$$

where $i = 1, 2, \dots, n - 1$ and

$$\boldsymbol{\eta} = [\eta_1, \eta_2, \dots, \eta_{n-1}]. \quad (6)$$

The derivative of the measurement signal after correction at point i is defined by the relationship:

$$y'_{corr-i} = \eta_i \frac{dy_i}{dt} \tag{7}$$

and

$$y'_{corr} = [y'_{corr-1}, y'_{corr-2}, \dots, y'_{corr-n-1}] \tag{8}$$

Figure 1 shows example values of the correction factor (formula 5) depending on the increments of the reference and measurement signals. For a single increment value dY , there may be two correction coefficient values, which is a characteristic feature of this coefficient. For this reason, in order to determine the correct correction factor in equation 5, it is necessary to apply an additional condition examining the positive or negative direction of changes in the measured data y . In Figure 1, the arrows indicate the direction of change in the increase in the Y variable. Based on the values of dy , y and the direction of their changes (\uparrow - indicates increasing values, \downarrow - decreasing values) a table of correction coefficient values $\eta(dy \uparrow\downarrow, y \uparrow\downarrow)$ is created. The table is used to determine the appropriate correction coefficient from equation 7.

During the correction process, two consecutive measured values are read, and their increment and direction of change are determined. Based on the data obtained, the correction coefficient value is read and applied to the correction equation (equation 7).

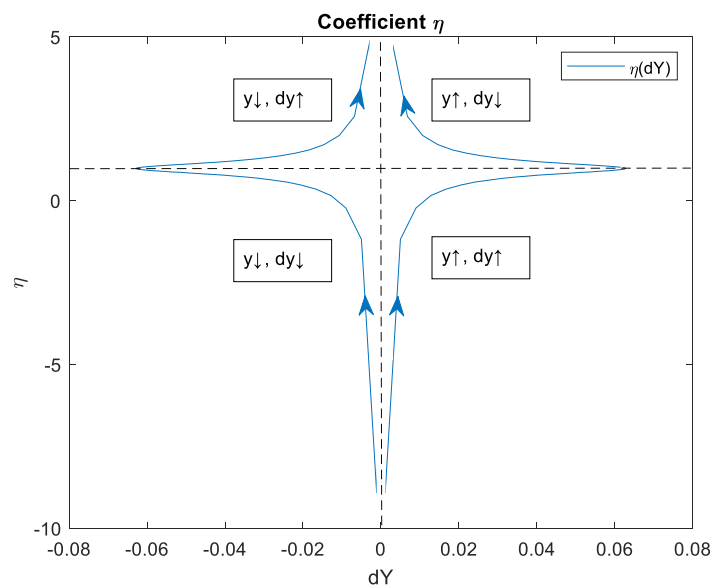


Fig. 1. Example characteristics of the dependence of the correction coefficient on signal values and increments

3 RESULTS

3.1 PHASE SHIFT CORRECTION

The operation of the correction method is shown for a sinusoidal signal with a frequency of 100Hz sampled at a frequency of 10,000 Hz. The measured signal is shifted in phase relative to the reference signal by 10° (Fig. 2). The values of the derivatives of the reference and measured signals are shown in Fig. 3.

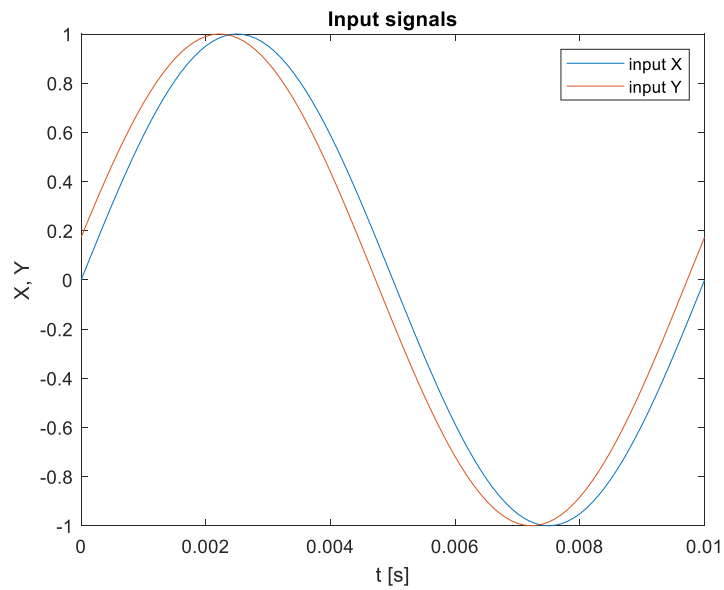


Fig. 2. Signals: reference and measurement

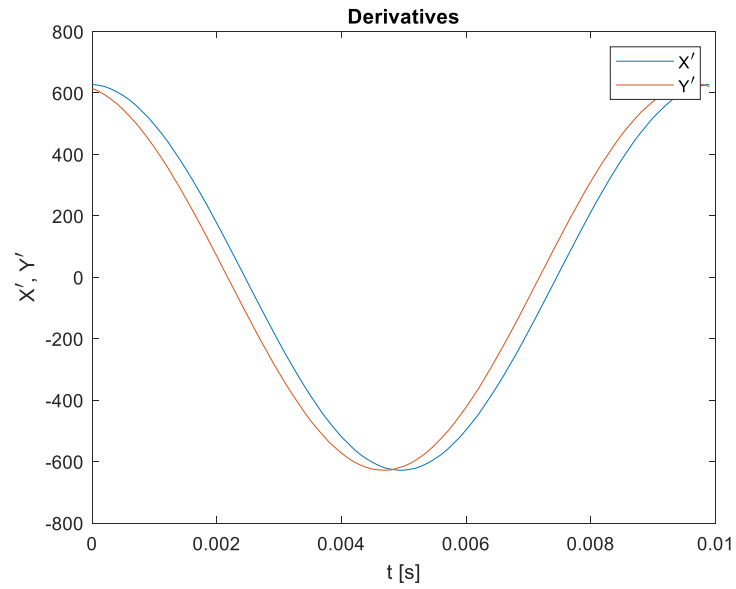


Fig. 3. Derivatives of reference and measurement signals

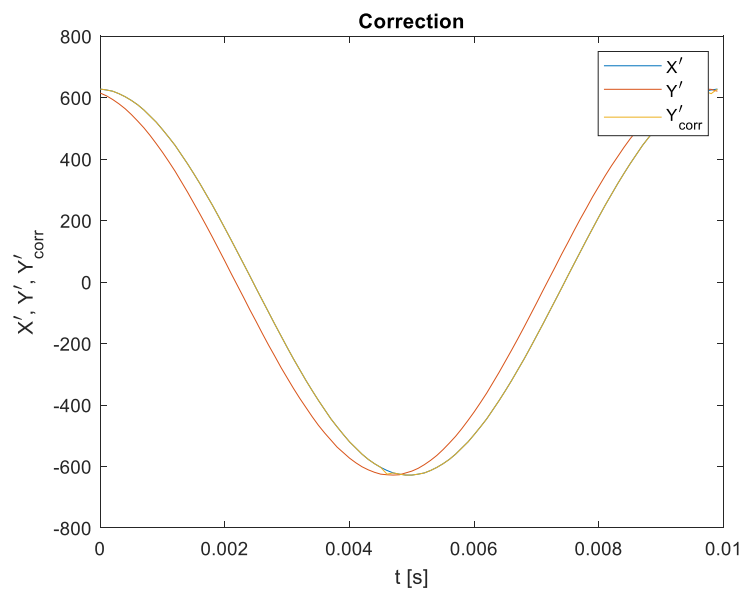


Fig. 4. Signal derivatives: reference X' , measured Y' and measured after correction Y'_{corr}

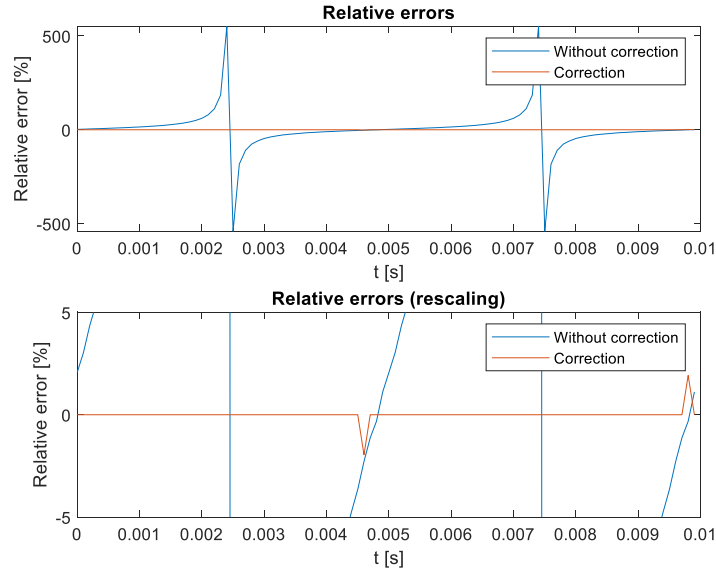


Fig. 5. Relative signal errors: measured Y' and measured after correction Y'_{corr}

Fig. 4 compares the derivatives of the signals: reference: X' , measured Y' and measured after correction Y'_{corr} . Figure 5 shows the error waveforms of the measured and measured after correction signals. Table 1 shows the obtained error values.

Table 1. Relative errors – phase shift correction

Relative error	Without correction	Correction
Minimum [%]	-540	-1.958
Maximum [%]	550	1.92
Mean [%]	1.618	-0.0003759
Median [%]	1.592	-1.958

3.2 AMLITUDE AND PHASE SHIFT CORRECION

Figure 6 shows the reference and measurement signals with an amplitude 1.2 times greater than the reference signal and shifted in phase relative to the reference signal by -10° . Both signals have a frequency of 100 Hz and are sampled at a frequency of 10,000 Hz. Fig. 7 shows the derivatives of the signals, Fig. 8 shows the correction effect (the characteristics X' and Y'_{CORR} overlap), and Fig. 9 shows the measurement errors before and after correction. Table 2 summarises the error values.

Table 2. Relative errors – phase shift and amplitude correction

Relative error	Without correction	Correction
Minimum [%]	-670	-1.995e-14
Maximum [%]	635	2.075e-14
Mean [%]	-18.18	-1.089e-16
Median [%]	-18.15	0

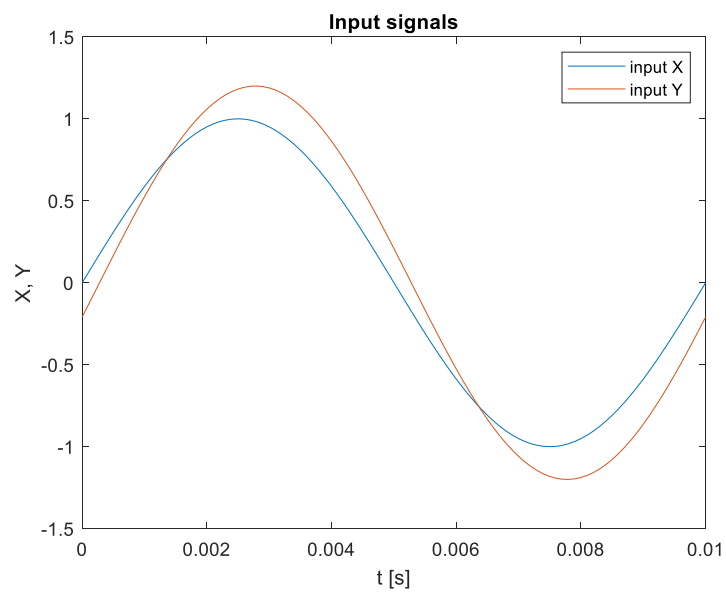


Fig. 6. Reference and measurement signal – shifted in phase and amplitude

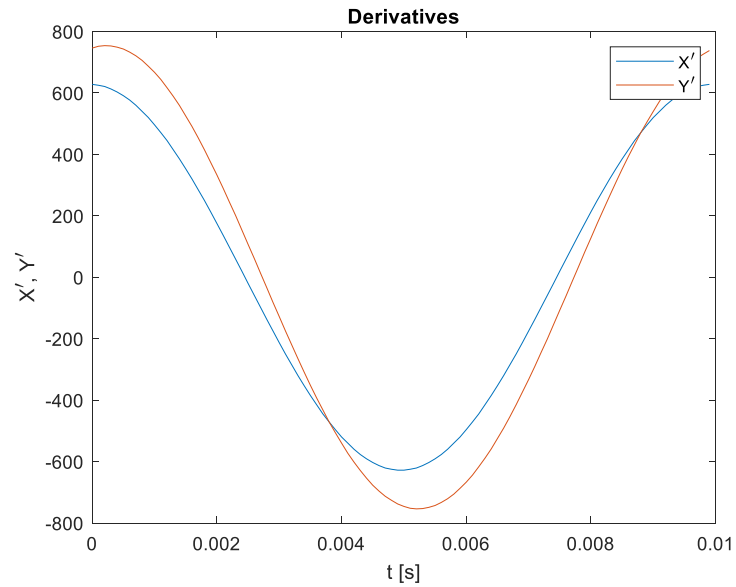


Fig. 7. Derivatives of reference and measurement signals with phase and amplitude shift

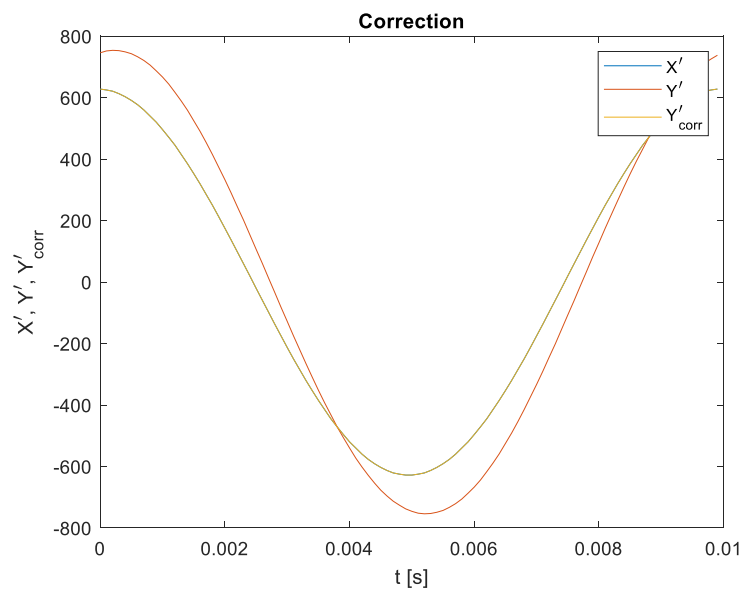


Fig. 8. Signal derivatives: reference X' , measured Y' and measured (with phase and amplitude shift) after correction Y'_{corr}

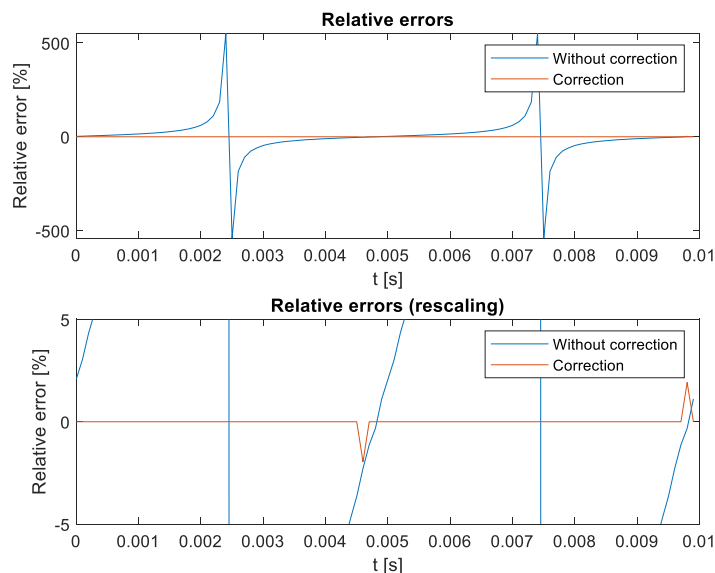


Fig. 9. Relative signal errors: measured Y' and measured (with phase and amplitude shift) after correction Y'_{corr}

4 CONCLUSIONS

The presented method of measurement data correction can be used in measurement transducers containing DSP circuits or any other circuits in which measurement errors can be corrected by prior calibration and saving correction coefficients in tables contained in memory circuits. The presented method is notable for its high effectiveness in relation to various types of errors: phase shift and amplitude error. The method is more effective when these two errors occur together.

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