CALIBRATION OF ACCELEROMETRIC MULTISENSOR SYSTEM

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Summary. Noise of sensors is the typical problem in each sensor application. One of the methods of the noise reducing is the parallel sensor connection method. The presented article describes the creation of an acceleration sensor by using this method. Sensor noise characteristics were measured previously [1]. The calibration parameters were obtained by the multiposition test of the sensor. Measured data are presented together with the calibrated data. Additive and multiplicative constants are determined.

Keywords: accelerometer, multiposition test, noise reduction

1. INTRODUCTION

The article deals with the calibration of an acceleration multisensor and refers to the previous work [1] focused on the increasing of the Signal-to-Noise Ratio (SNR) by the method of the parallel sensor connection. The basic metrological properties of such multisensor are discussed in the article.

The subject of the research was the multisensor of acceleration created by the synthesis of nine analogue accelerometers ADXL 335. The accelerometers were placed on a printed circuit board (PCB) in the shape of 3 x 3 matrix. Output of each sensor was connected to the summation amplifier.

The ADXL 335 is three-axis analogue MEMS acceleration sensor with small power consumption. The noise level of the sensor is 150 μg/√Hz RMS in *X* and *Y* axis. In the *Z* axis the noise floor is 300 μg/√Hz RMS [2]. Previous measurements proved that the parallel connection of nine sensors decreases the noise RMS value in the output signal. The decrease was 13.56 dB in the *X* axis, 13.47 dB in the *Y* axis and 11.87 dB in the *Z* axis [1].

Further logical step of our work was the multiposition test [3]-[6]. This measurement was performed on a turning platform with the rotation around all three axes. The main idea of this test is to change the direction of the gravitation vector actuating on the created multisensor. The range of the gravitational acceleration is ±1 g. The sensor output values were recorded in 36 positions of the rotating platform. Multiposition test characteristics were created based on the measured data. The offline calibration was consequently performed on the recorded data and the calibration parameters were obtained.

2. THEORY

Each real source of a signal is loaded by an internal noise. Its amount in the signal can vary in dependence on the kind of the source and the external influences. The signal quality with respect to the noise amount is defined by the SNR (Signal to Noise Ratio). To supress the noise influence several methods can be used mostly based on the signal filtering. Another method frequently used in low noise analogue circuits is the method of the parallel signal source connection. The method is based on these fundamental assumptions [7]:

1. Deterministic signals are summed as follows:

$$U = U_1 + U_2 + U_3 + U_4 + \cdots U_n \qquad 1.$$

where U is the RMS value of the sensor voltage.

2. Stochastic signals are summed as follows:

$$V = \sqrt{{V_1}^2 + {V_2}^2 + {V_3}^2 + {V_4}^2 + \cdots {V_n}^2} \qquad 2.$$

where V is the RMS value of the sensor noise.

For illustration, if there are four equal sources of signal with 2 V signal amplitude and 2 mV noise amplitude, than based on the previous equations after summation of these signals we get signal with 8 V signal amplitude and 4 mV noise amplitude. The noise was increased twice in comparison with the signal, which was increased four times. The SNR increased by 6.06 dB in comparison to one single signal source.

3. EXPERIMENTS AND RESULTS

The acceleration multisensor was created according to the schematics presented in Figure 1. Each channel included a summation amplifier. The sensors were placed near each other on the PCB in the shape of 3 x 3 matrix. Orientation of the sensors axes with respect to the PCB was identical for all sensors.

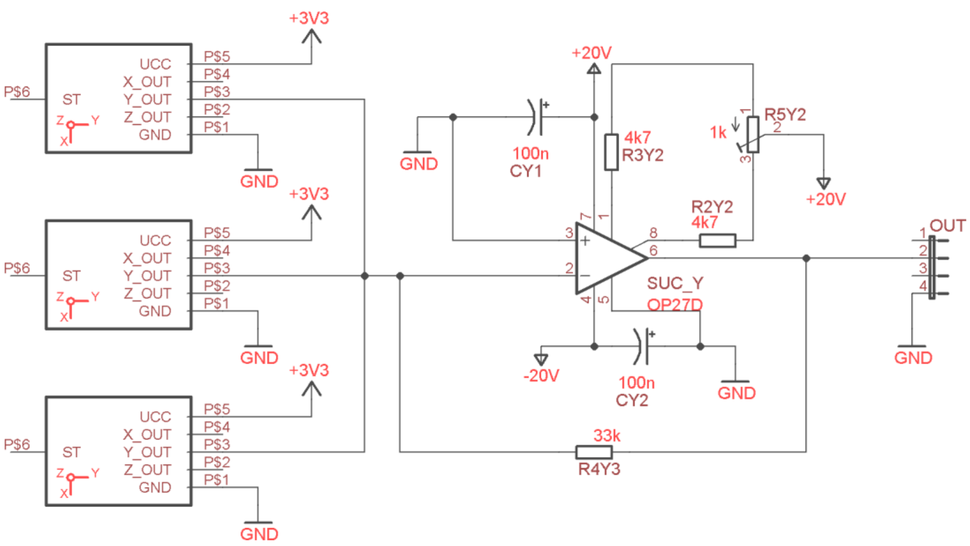

Figure 1 Schematics of *Y* channel and summation amplifier of the multisensor

The multisensor was connected to the measurement station during the tests. Block diagram of the measurement station is presented in Figure 2.

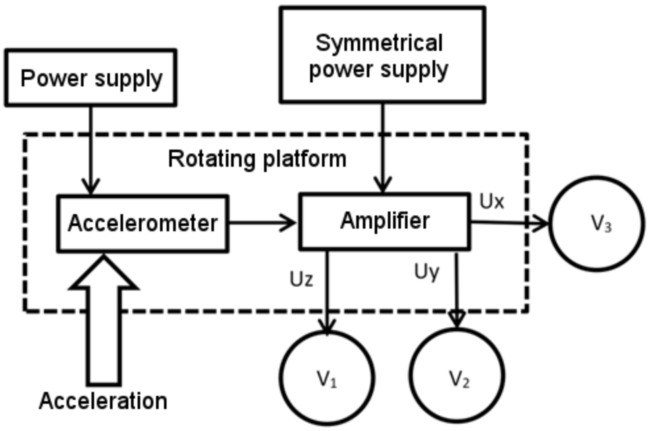

Figure 2 Block diagram of the measurement station for calibration

The multisensor was supplied by the 2.7 V DC supply voltage. The summation amplifier was supplied by ±12 V DC supply voltage. The Agilent 34401A multimeter was used as the voltmeter. The sensor was placed on the rotation platform in the plane of the gravitation force. The gravitation vector influence was changed in sequential 10° step rotation of the platform in range ±1 g. Measured data are presented in the Figure 3 as a function of the angular position.

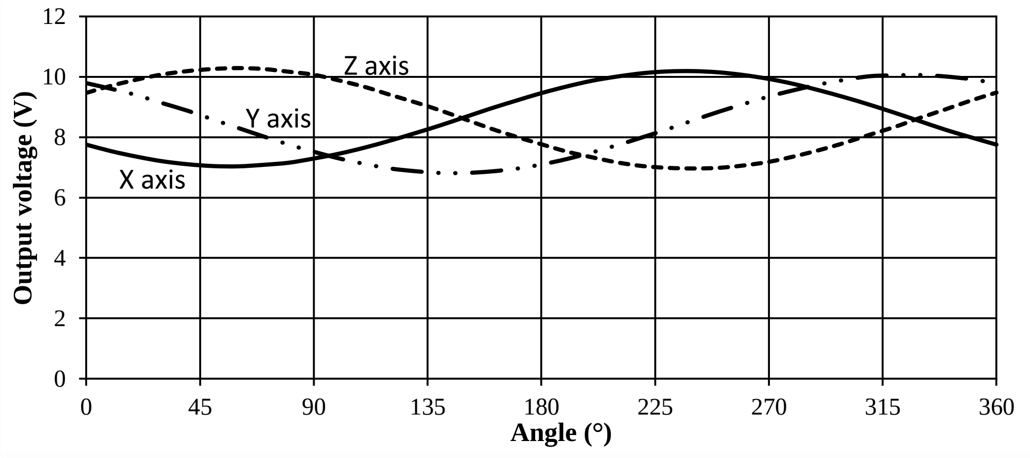

Figure 3 Change of sensor output voltage in dependence on the angular position

The additive constants values were determined from the measured data by:

$$U_{additive} = \frac{1}{n}\sum_{i=1}^{n} U_i \qquad 3.$$

where U_i is the measured voltage value and n is the number of measurements.
Values of additive constants are presented at Table 1.

Table 1 Additive constants of the multisensor

Axes	*X*	*Y*	*Z*
Additive constant (V)	8.58	8.47	8.65

The measurement can be corrected for the additive error by:

$$U_{calibrated} = U_i - U_{additive} \qquad 4.$$

The measured values of the output voltages corrected by the additive constants are presented in Figure 4.

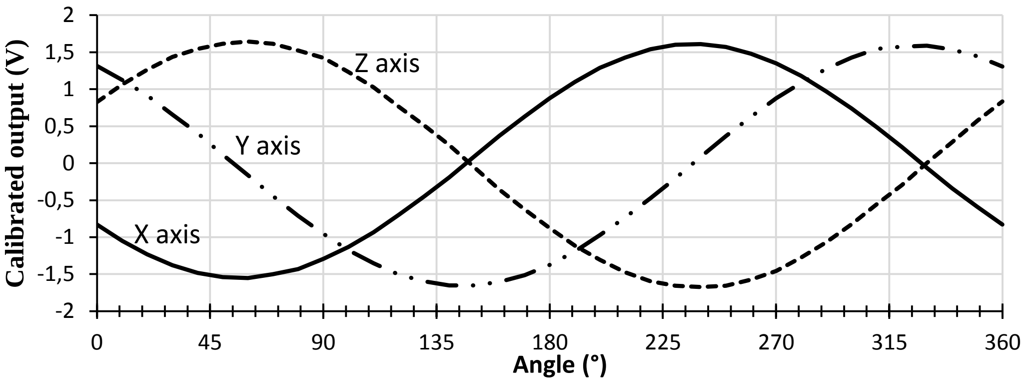

Figure 4 Change of sensor output voltage in dependence on the angular position corrected for the additive errors

The sensitivity of the multisensor was estimated. The sensitivity is defined as the ratio between the change of the sensor output quantity and change of the input quantity

$$c = \lim_{\Delta x \to 0} \left(\frac{\Delta y}{\Delta x}\right) = \frac{df(x)}{dx} \qquad 5.$$

The input quantity is acceleration and the output quantity is the voltage for an analogue sensor. The multiplicative constant has the dimension of V/g. The multiplicative constants were determined by:

$$c = \frac{U_{PP}}{2} \qquad 6.$$

where the U_{PP} is the peak to peak voltage.
The multiplication constants values are presented in Table 2.

Table 2 Multiplicative constants of the multisensor.

Axes	*X*	*Y*	*Z*
Sensitivity (V/g)	1.58	1.62	1.66

Correction to the additive and multiplicative errors was taken into the measurement by:

$$U_{calibrated} = \frac{U_i - U_{additive}}{c} \qquad 7.$$

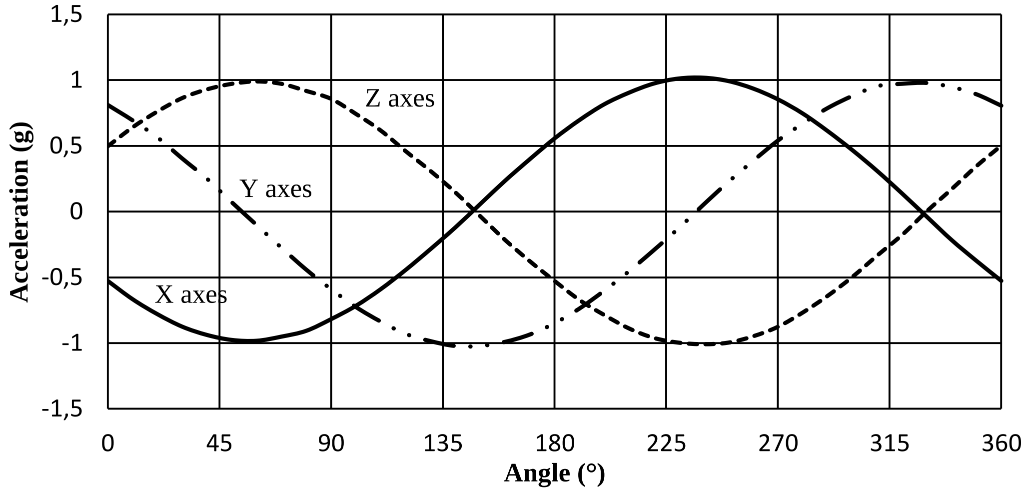

Figure 5 Dependence of multisensor output voltage on angular position corrected for the additive and multiplicative errors

CONCLUSION

The acceleration multisensor was created as a one of the method of noise reduction in the analogue sensor output signal. This method is based on the assumption that the summation of the deterministic signals is linear while the summation of the stochastic signals is under the square root. The presented multisensor was created by the parallel connection of nine analogue accelerometers ADXL 335. The noise of sensor output was reduced on an average for 11.97 dB.

The multisensor was calibrated by the multiposition test. The test is based on rotating of the multisensor in the gravitation field which induce the acceleration into the sensor axes in range ±1 g. Measured data were calibrated for the additive and multiplicative errors. The additive error was estimated as 8.58 V for the *X* axis, 8.47 V for the *Y* axis and 8.65 V for the *Z* axis. The additive error is relatively high because the sensor is non-symmetrically supplied. The zero output value is in the half of the sensor supply voltage. Compensation for the multiplicative error was estimated as 1.58 V/g for the *X* axis, 1.62 V/g for the *Y* axis and 1.66 V/g for the *Z* axis. The sensitivity of the single ADXL 335 sensor is 0.3 V/g. The presented multisensor reaches the 5.4 times higher sensitivity on average than the single sensor.

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