Analysis of the thermal effect influence on the MEMS accelerometer sensors measurement results

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ABSTRACT

In the study the results of the thermal effect influence on the measurements of three different analog accelerometer sensors (ADXL335, ADXL327, LIS344ALH) and one digital sensor (MPU-9255) are presented. The measurement data was registered within the -2°C ÷ 65°C temperature range. The first part of the article characterizes the procedure of determining the acceleration for analog and digital sensors. Moreover, the study includes the methods of determining parameters such as Zero-g Offset and sensitivity. The temperature parameters of the accelerometers, such as Sensitivity change vs. Temperature and Zero-g Offset vs. change Temperature, were also determined. The indicators were determined separately for each of the OX, OY, OZ axes for the investigated MEMS sensors. Finally, the obtained results were compared with the parameters guaranteed by the accelerometric sensor manufacturers.

Keywords: Temperature compensation, MEMS sensors, inertial sensors

1. INTRODUCTION

The development of modern interactive techniques resulted in the need of using inertial sensors in various kinds of the electronic devices. Integrated circuits of small size in the form of MEMS (Micro Electro-Mechanical Systems) sensors are usually used for this purpose. These devices differ from each other in temperature range, accuracy, resolution, and, most importantly, in the type of functioning. Among them, the magnetometers measuring the magnetic field, gyroscopes measuring angular velocity and accelerometers that measure acceleration, can be distinguished. All of them, connected with each other, are suitable for estimating the orientation and reflect the position of an object in the 3D space. Unfortunately, the inertial electronics proves to be sensitive to temperature changes [1-3]. Due of this fact, the measurements might be prone to errors. In the case of using sensors to estimate the orientation or velocity of an object, the described phenomenon significantly deteriorates the obtained results. Therefore, it is necessary to conduct appropriate studies, during which the analysis of the influence of temperature on these electronic components would be carried out. The performance of this kind of studies does not appear to be easy because of the need to have adequate technical facilities to enable e.g. regular temperature changes.

In this study, the authors describe a laboratory stand for thermal accelerometers testing. The studies determined the temperature influence on the measurements obtained by the selected acceleration sensor. During the temperature analysis of each accelerometers axis, the corrections characteristics of the temperature impact on the value of the read acceleration were revealed. The tests that enable the estimation of the temperature drift were conducted. Such information, with the use of appropriate numerical calculations, allows to increase the accuracy of accelerometers measurements. Parameters such as Zero-g Offset and sensitivity give other extremely important information used, for example, to construct IMU or AHRS systems. They are given by the manufacturers in the directory notes. Unfortunately, even the last ones are also sensitive to temperature changes. Then, it is important to appoint Zero-g Offset change vs. Temperature or Sensitivity change vs. Temperature parameters, as it was done in this work.

2. DESCRIPTION OF THE LABORATORY STAND

In order to determine the temperature parameters, a specially constructed measurement stand was used. It included a climatic chamber, tested accelerometers, NI cDAQ-9171 measurement card with an NI 9220 module, a microprocessor system with an ATmega328 microcontroller and a data acquisition system developed in LabVIEW (Figure 1). The measurement systems connected to a computer were sending data in the form of integer numbers, which represent the states of analog-to-digital converter (data from ADXL335, ADXL327, LIS344ALH analog accelerometers) and digital measurement data of the MPU-9255 system. It also should be underlined that all tested sensors were characterized by ± 2 g ÷ ± 3.6 g operating range [7-10].

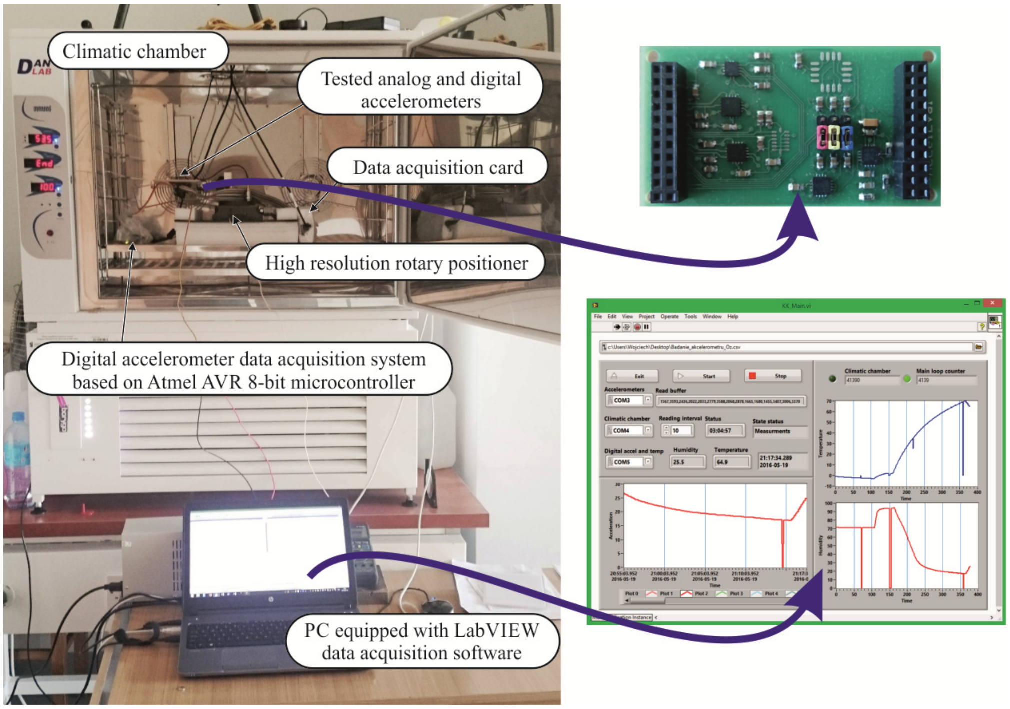

Figure 1. General view of the laboratory stand.

In the course of the study, the measurements for each of six different orientations of the accelerometers were recorded. The research was carried out in the cases where acceleration of gravity, within the range of +1 g or -1g, operated on one of the axes [4-6]. Thus, the obtained orientations were labeled as OZ+, OZ-, OX+, OX-, OY+, OY-. It is worth mentioning that the arrangement of the integrated circuits in relation to the gravitational acceleration vector requires special preservation accuracy. Therefore, in order to provide specific plates deflection, a rotatory positioner was used (Fig. 2).

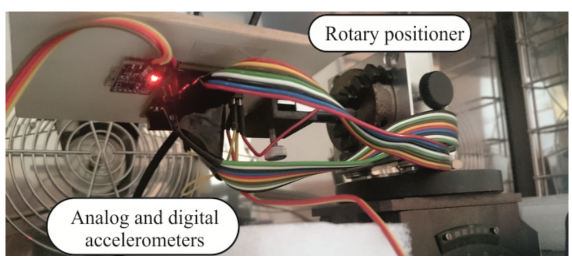

Figure 2. View of rotary positioner with accelerometer placed on the PCB pates.

One of the most important elements of the measurement system was a virtual instrument implemented in the LabVIEW environment. This solution enables automating the measurement process. It was possible with the use of an external device that exploits the USB communication interface. In addition, the developed program canceled the need for direct monitoring of a long-term measurement process and reduced the probability of the reading error during the measurements. Moreover, this method eliminates the necessity of using the external measurement equipment and signal conditioners.

3. THE RESULTS OF LABORATORY TESTS AND METHODS FOR DETERMINING ACCELERATION PARAMETERS

The measurement procedure, assumed in the research, started with determining a certain orientation of the accelerometer situated in the climatic chamber. Then, the message concerning the initiation of the cooling process to the temperature value of -2 ºC was sent to the chamber. Achieving the setpoint started the measurement data acquisition process and the chamber heating process. The measurement ended automatically, at the moment of achieving the limiting setpoint, e.g. 65 ºC. The algorithm of the described procedure is presented in figure 3.

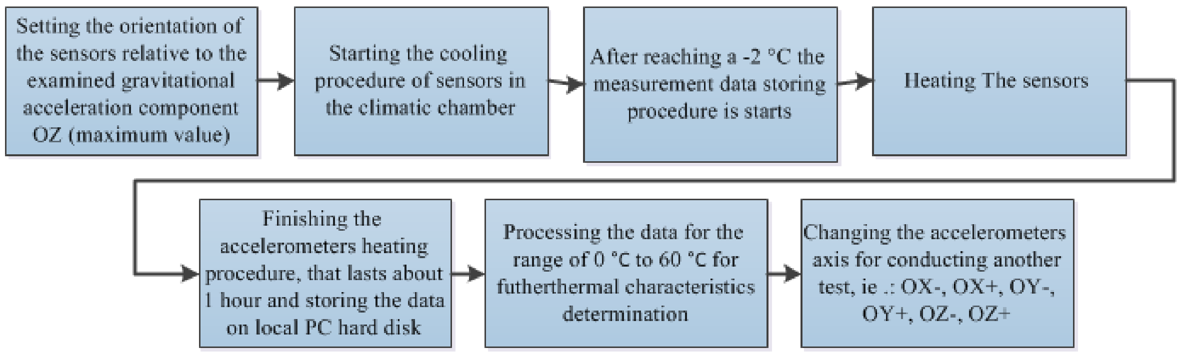

Figure 3. The algorithm of accelerometers testing procedure conducted in the climatic chamber.

It should be noted, that for further analysis, the data from the interval of 0 ºC to 60 ºC, rather than -2 ºC to 65 ºC, was used. It was related to the fact that in the limiting points of -2 ºC to 65 ºC, the unstable phenomenon of the temperature rise inside the climate chamber may occur. Moreover, during the tests, the authors ensured that the chamber heating process would be long enough to achieve the expected temperature for each of the studied accelerometers. It is also worth mentioning that the measurement signal was read at a 20 Hz frequency, and then subjected to the additional process of averaging. The final measurement data was recorded at the frequency of 2 Hz. Additionally, the stability of the vibration environment and the laboratory stand were ensured. It was also ensured that the sensor remained motionless.

The use of the described process of data acquisition resulted in a number of data registration as a function of the temperature increase. This information was subjected to the next phase of the additional averaging process. Then, on its basis, the linear approximation was done. Figure 4 shows an exemplary characteristics of the OZ axis of ADXL335Z accelerometer before and after data processing.

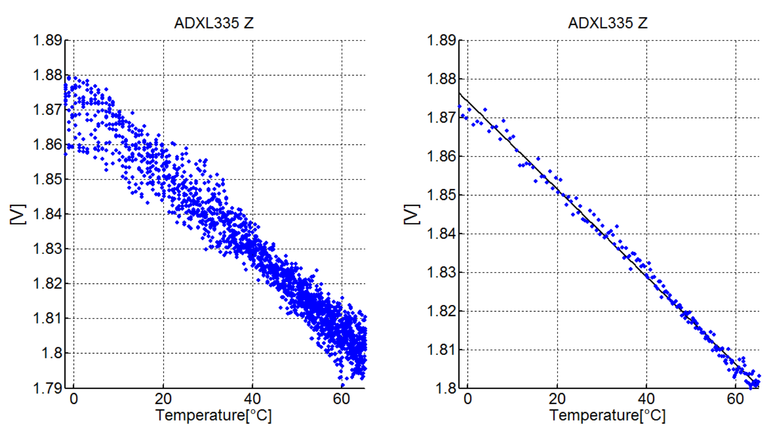

Figure 4. Visualization of the exemplary data for the ADXL 335Z accelerometer.

The procedure of acceleration determination for analog sensors on the basis of an ADXL335 accelerometer example

Below, an example of the accelerations determination on the basis on measurements from ADXL335 accelerometer is presented. The sensor was supplied by an external source of 3.0 V voltage and the temperature was 25 ° C. To determine the sensor parameters, the application note of the accelerometer was additionally used. The accelerometer data is shown in Table 1.

The data acquisition was carried out with the use of a program created in the LabVIEW environment. The programming package contained a set of libraries and components for servicing an NI cDAQ-917 measurement card. The values read by the ADC transmitter were scaled automatically to the values expressed in volts. Exemplary measurement data is given in equation (1).

Table 1. An excerpt of a directory notes of an ADXL335 accelerometer [7].

Parameter	Conditions	Min	Typ	Max	Unit
Measurement Range		±3	±3.6		g
Sensitivity at X_{OUT} , Y_{OUT} , Z_{OUT}	V_s=3 V	0.27	0.30	0.33	V/g
Sensitivity Change Due to Temperature	V_s=3 V		±0.01		%/°C
Zero-g Offset at X_{OUT} , Y_{OUT}		1.35	1.5	1.65	V
Zero-g Offset at Z_{OUT}		1.2	1.5	1.8	V
Zero-g Offset vs. Temperature			±1		mg/°C

$$V_x = 1.4810 \text{ V} \quad V_y = 1.4795 \text{ V} \quad V_z = 1.8472 \text{ V} \tag{1}$$

Accelerometer indications are burdened with the A zero-g offset (Table 1), which must be subtracted from the indications in accordance with equation (2) [4-5].

$$\begin{aligned} \mathit{\Delta} V_x &= \left(V_x\text{-}V_{0g}\right) \approx \text{-}0.0190 \text{ V} \\ \mathit{\Delta} V_y &= \left(V_y\text{-}V_{0g}\right) \approx \text{-}0.0205 \text{ V} \\ \mathit{\Delta} V_z &= \left(V_z\text{-}V_{0g}\right) \approx 0.3472 \text{ V} \end{aligned} \tag{2}$$

The result of previous operations is the acceleration calculated value expressed in volts. For its final conversion into units of the gravitational acceleration g, the determined value (2) must be divided by the value of sensitivity (Table 1), as presented in equation (3).

$$\begin{aligned} a_x &= \Delta V_x / Sens = \text{-}0.0635 \text{ g} \\ a_y &= \Delta V_y / Sens = \text{-}0.0684 \text{ g} \\ a_z &= \Delta V_z / Sens = +1.1572 \text{ g} \end{aligned} \tag{3}$$

In the analyzed case, when the body is not subjected to an external force, the sum of the components of each accelerometer axis should be 1.0 g (4) [4]. In the present case, this condition is not fulfilled. Therefore, it is necessary to calibrate the system.

$$a_x^2 + a_y^2 + a_z^2 = 1.3479 \neq 1 \tag{4}$$

The procedure of acceleration determination for the MPU-9255 digital sensor

Below, an example of acceleration determination on the basis of the measurement data acquired from the analog accelerometer on the example of a MPU-9255 element is presented. The described motion sensor was equipped with the I2C communication interface and an integrated 16-bit ADC. Similarly to the accelerometer described previously, the element was supplied with 3.0 V. The measurement recording was also performed at 25 ° C temperature. A part of a application notes [10] of the element is presented in Tab. 2.

The unprocessed measurement data (e.g. Raw Data), is presented in equation (5).

$$A_x = 402 \qquad A_y = 574 \qquad ADC_z = 16714 \tag{5}$$

Table 2. A part of a application note of MPU9255 accelerometer [10].

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	AFS_SEL=0		±2		g
	AFS_SEL=1		±4		g
ADC Word Length Output in two's complement format			16		bits
Sensitivity Scale Factor	AFS_SEL=0		16.384		LSB/g
	AFS_SEL=1		8.192		LSB/g
Sensitivity Change vs. Temperature	-40 °C to +85 °C AFS_SEL=0		±0.026		%/°C
Zero-g Initial Calibration Tolerance	Component-level X,Y		±60		mg
	Component-level Z		±80		mg
Zero-g Level Change vs. Temperature	-40 °C to +85 °C		±1.5		mg/°C

This data should be scaled to the g units. It is performed according to the sensitivity parameter, which is stated in Tab. 2.

$$a_x = A_x / Sens = 0.0245 \quad a_y = A_y / Sens = 0.0350 \quad a_z = A_z / Sens = 1.0201 \tag{6}$$

As in the previously analyzed case, the total acceleration vector exceeds 1 g.

In the case of digital accelerometers, there is no equivalent of the Zero-g Offset parameter, that is defined in the case of analog accelerometers. Additionally, the sensitivity parameter is described without the minimum, typical and maximum values. In real projects, the subsequent calibration of this type of accelerometers is often carried out. In such a case, Zero-g Offset as well as sensitivity parameters are determined individually for each test axis.

The determination of the Zero-g Offset parameter for the tested sensors

The determination of the Zero-g Offset parameters required conducting at least two measurements. The first one was implemented in the case where the axis of the accelerometer was subjected to the acceleration of about 1 g. Another one was implemented in the case of a change of orientation to -1 g. On this basis, the characteristics of the output voltage as a function of the acceleration was established [6]. Equation (7), that describes the conversion of the 1 g or -1 g voltage to the scaled output voltage and the visualization of an exemplary waveform characteristics (Fig. 5) is shown below.

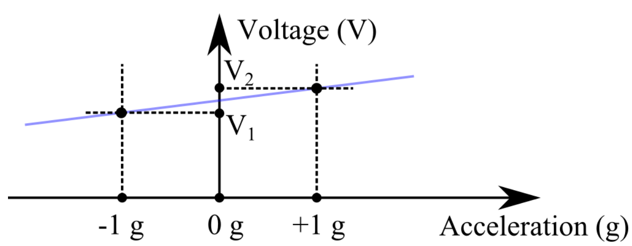

Figure 5. The characteristics of accelerometer processing [6].

$$V_{OUT} = \frac{(V_2 - V_1)}{(g_2 - g_1)} \cdot g + V_{0g} \tag{7}$$

In the analyzed case (registration acceleration -1 g or +1 g), the V_{0g} voltage constitutes the arithmetic mean of V_2 and V_1 indications as illustrated in equation (8). This equation can be based on the geometry dependence that describes the coordinates of the center segment.

$$V_{0g} = \frac{(V_1 + V_2)}{2} \tag{8}$$

The determination of the Sensitivity parameter

The sensitivity parameter is determined according to equation (9), described in [4,6].

$$S = \frac{(V_2 - V_1)}{(g_2 - g_1)} \tag{9}$$

where: V_1 is the voltage read at the time of g_1 acceleration, V_2 is the voltage read at the time of g_1 acceleration g_2.

In this case, the formula simplifies to the following form:

$$\begin{matrix} g_1 = -1.0 \\ g_2 = +1.0 \end{matrix} \Rightarrow S = \frac{(V_2 - V_1)}{2} \tag{10}$$

The results of determining the Sensitivity and Zero-g Offset parameters

In the first part of the study, the sensitivity and Zero-g Offset parameters were determined and their comparison with the catalogue data was made. The parameters guaranteed by their manufacturers were specified for the T = 25 ° C temperature. Consequently, they were presented as the values obtained on the basis of the measurements recorded at a specified temperature. It should be mentioned that the manufacturers of MEMS sensors provide parameters in the following convention: the minimum, typical and maximum value. There is a widespread trend of giving both the sensitivity and Zero-g parameters in the compartments, sometimes of a great value. The summary of settings guaranteed by the manufacturers and appointed on the basis of the recorded measurements are shown in Tab. 3. The described parameters were calculated for each axis of the accelerometers individually. Their values are within the ranges provided by the manufacturers.

On the example of the ADXL335 accelerometer (Table 3), the fact that the acceleration value of +1 g could be represented by voltage between 1.47 V ÷ 2.13 V, could be established. Such a wide range proves the absolute necessity of the sensor calibration.

Table 3. Comparison of catalogue data [7-9] with the determined parameters.

		ADXL335				ADXL327				LIS344ALH			
		Datasheet Data			Measured Data	Datasheet Data			Measured Data	Datasheet Data			Measured Data
		min	typ	max		min	typ	max		min	typ	max	
Sensitivity [V/g]	X				X 0.293				X 0.408				X 0.586
	Y	0.270	0.300	0.330	Y 0.295	0.378	0.420	0.462	Y 0.405	0.570	0.600	0.630	Y 0.588
	Z				Z 0.305				Z 0.415				Z 0.604
Zero-g Offset [V]	X	1.350	1.500	1.650	X 1.498	1.300	1.500	1.700	X 1.496				X 1.517
	Y				Y 1.485				Y 1.491	1.425	1.500	1.575	Y 1.515
	Z	1.200	1.500	1.800	Z 1.541	1.200	1.500	1.800	Z 1.667				Z 1.535
+1g [V]	X	1.620	1.800	1.980	X 1.791	1.678	1.920	2.162	X 1.904				X 2.103
	Y				Y 1.780				Y 1.897	1.995	2.100	2.205	Y 2.103
	Z	1.470	1.800	2.130	Z 1.846	1.578	1.920	2.262	Z 2.082				Z 2.139
-1g [V]	X	1.080	1.200	1.320	X 1.205	0.922	1.08	1.238	X 1.089				X 0.930
	Y				Y 1.189				Y 1.086	0.855	0.900	0.945	Y 0.928
	Z	0.930	1.200	1.470	Z 1.237	0.822	1.08	1.338	Z 1.252				Z 0.931

The comparison of the digital accelerometer measurements given in the application note and obtained on the basis of the measurements is presented in Tab. 4. The values of the Sensitivity parameter is slightly different from the expected values given in the application note. However, in the case of the MPU-9255 accelerometer, the manufacturer does not establish the Zero-g Offset parameter. It is easily observable that this parameter for the Y- and Z- takes on small values. Unfortunately, for the X-axis, this parameter can take a significant value. An example application of such an accelerometer used for the orientation estimation of the object, with the use of an uncalibrated accelerometer, would have a significant error. It is unacceptable in uses associated with, for example, robotics. For this reason, the calibration procedure for such an element should be previously carried out.

Table 4. The comparison of the catalogue data [10] with the data appointed from the digital accelerometer parameters.

	MPU-9255			
	Sensitivity [LSB/g]	Zero-g Offset [LSB]	+1 g [LSB]	-1 g [LSB]
Datasheet Data	16 384	-	16 384	-16 383
Measured Data	X 16313	X -220	X 16093	X -16534
	Y 16365	Y 89	Y 16454	Y -16277
	Z 16592	Z 128	Z 16720	Z -16463

4. WYZNACZENIE PARAMETRÓW TEMPERATUROWYCH BADANYCH AKCELEROMETRÓW/ DETERMINING THE TEMPERATURE PARAMETERS OF THE TESTED ACCELEROMETERS

The producers, in the application notes, indicate two parameters concerning the temperature effect on the indications of the previously discussed parameters. One of them is Sensitivity vs. Temperature change, which describe the effect of the temperature change on the sensitivity. It is expressed in the %/°C unit. Another one reflects the influence of temperature on the value of the Zero-g Offset parameter. It is expressed in the mg/°C unit. The aim of the studies, presented in this chapter, is to compare the determined parameter with the data given in the catalogue notes. Firstly, the parameters associated with the accelerometers sensitivity change were determined. Then, the obtained data was used to determine the offset temperature.

Sensitivity change vs. Temperature

The Sensitivity change vs. Temperature parameter describes the influence of the Sensitivity parameter on temperature. If the parameter value is ± 0.01% / ° C, the temperature change from 25 ° C to 60 ° C is about the sensitivity change parameter of ±0.01 mg/° C· (60 ° C-25 °C) = 0.35%. This value is negligible, which proves the ability of neglecting this phenomenon [2,11].

In order to determine the Sensitivity change vs. Temperature parameter, the sensitivity parameter determination was made within a wide temperature range. Tab. 5 shows the comparison of the parameters provided by the manufacturers and determined on the basis of the research.

Table 5. The comparison of the catalogue data [7-10] with the determined parameters.

		Sensitivity change vs. Temperature [%/ºC]			
		ADXL335	ADXL327	LIS344ALH	MPU-9255
Datasheet Data		±0.010	±0.010	±0.010	±0.026
Measured Data	x	0.005	0.001	-0.041	0.000
	y	-0.002	0.000	0.011	-0.004
	z	-0.012	-0.010	0.002	-0.012

Fig. 6 shows the summary of the sensitivity values as a function of temperature for four tested accelerometers.

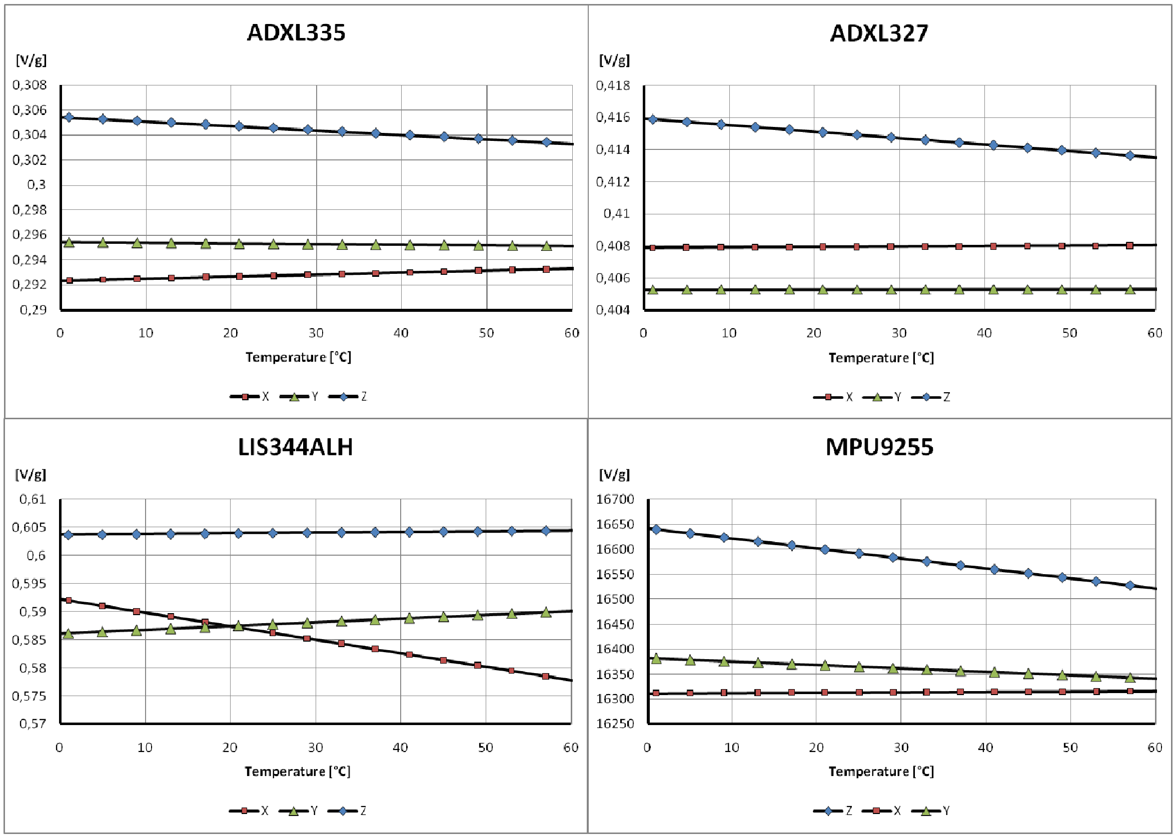

Figure 6. Sensitivity change vs. Temperature.

In the case of the Z axis of ADXL335 accelerometer, the expected change of the sensitivity parameter, for example in the case of the temperature increase from 25 ° C to 60 ° C, should be about ±0.01 %/°C·(60 °C-25 °C) = ±0.35%. With the sensitivity value of 0.305 (Table 3), this value should be 0.3061. As the result of the research, the expected sensitivity value is 0.3063. It is not significant and indicates the ability of neglecting the temperature compensation of the sensitivity parameter.

Zero-g Offset change vs. Temperature

The Zero-g Offset change vs. Temperature parameter describes how the level of the Zero-g Offset is dependent on temperature. If case Zero-g Offset change vs. Temperature parameter value is ± 0.4 mg / ° C, change in temperature from 25 ° C to 60 ° C should change the parameter Zero-g Offset by the value of ±0.4 mg/°C ·(60 °C-25 °C) = ±14 mg. This value is much smaller than the gravitational acceleration. Therefore, it may indicate the ability of neglecting this phenomenon [2,11].

In order to determine the Zero-g Offset change vs. Temperature parameter, the determination of the Zero-g Offset in a wide temperature range was performed. Fig. 7 shows the summary of the Zero-g Offset values as a function of temperature for four tested accelerometers.

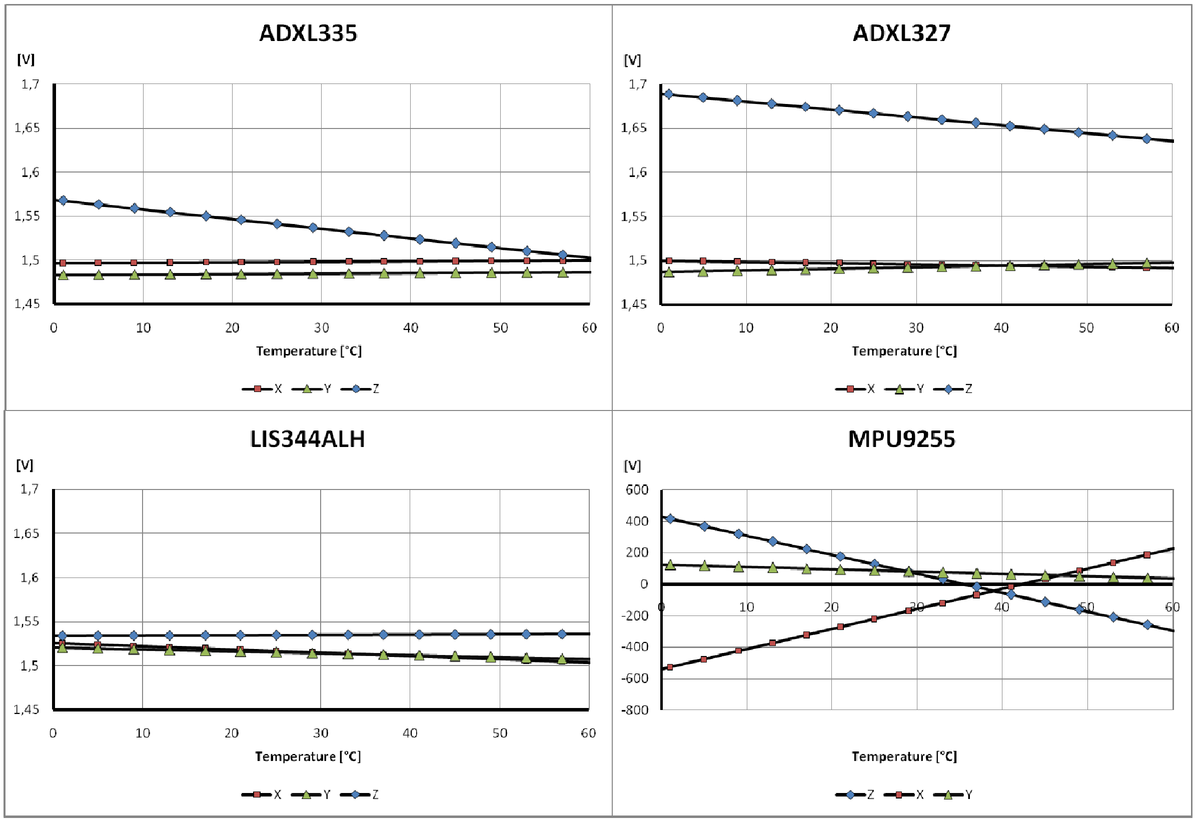

Figure 7. Zero-g Offset change vs. Temperature.

Table 6 shows the comparison of the parameters provided by the manufacturers and the parameters determined on the basis of the research. The Zergo-g Offset change vs. Temperature parameter was calculated after the prior value scaled to mg. As it is shown in the table, each accelerometer axis is characterized by a different coefficient. Additionally, in the case of every analog accelerometer, one of the axes had a value that exceeded the range given by the manufacturer. In the case of the digital accelerometer, the manufacturer does not provide either the Zero-g Offset or the Zero-g Offset vs. Temperature parameters.

Table 6. Comparison of the catalogue data [7-10] with the determined parameters.

		Zero-g Offset change vs. Temperature [mg/ºC]			
		ADXL335	ADXL327	LIS344ALH	MPU-9255
Datasheet Data		±1	±1	±0.4	---
Measured Data	x	0.185	-0.344	-0.636	0.783
	y	0.181	0.463	-0.378	-0.092
	z	-3.602	-2.164	-0.378	-0.726

In the case of the Z axis of the ADXL335 accelerometer, the expected change in the Zero-g Offset parameter, when the temperature increases from 25 ° C to 60 ° C, should be ±1 mg/°C·(60 °C-25 °C) = ±35 mg. In the case of the determined coefficient, this change should be about ±3.6 mg/°C·(60 °C-25 °C) = ±126 mg. This value is significant and proves the necessity of the temperature compensation implementation.

5. CONCLUSIONS

The aim of this study was to evaluate the effect of temperature on the accuracy of obtaining data from analog and digital MEMS accelerometers. Moreover, the comparison of the parameters provided by the manufacturers and the parameters determined on the basis of the research was performed. The study showed that the analysis of the effect of temperature and its compensation is extremely important for the use of accelerometers exploiting an IMU (Inertial navigation unit) or AHRS (attitude and heading reference system). Thanks to the appropriate correction methods of the measurement data obtained at different temperatures, the accuracy of the built-in inertial systems could increase. Therefore, it is reasonable to calibrate individual sensors used in these systems. Unfortunately, the main disadvantages of this solution are the necessity to position such a device in a climatic chamber and performing the protracted process of heating and cooling. As it turned out on the basis of the carried out tests, the basic parameters as presented in the application note are within the ranges given by the manufacturers. For example, in the case of Z axis of ADXL335 accelerometer, the expected change of sensitivity parameter, when the temperature increase of 25 ° C to 60 ° C should be 0.305, and it was 0.3061. However, this is not a significantly different value from the one specified by the manufacturer, it and indicates the ability of neglecting the temperature compensation of the sensitivity parameter. Notwithstanding, for the Z axis of the ADXL335 accelerometer, the expected change of the Zero-g, when the temperature increases from 25 ° C to 60 ° C, should be ± 35 mg, and it was ± 126 mg. This means that this value is so significant that it is necessary to use an appropriate temperature compensation.

6. ACKNOWLEDGEMENT

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REFERENCES

[1] Mackley, J. and Nahavandi, S. , "Active temperature compensation for an accelerometer based angle measuring device", Automation Congress, Proceedings. World (Volume:16), Pages:383 – 388 (2004).

[2] IEEE Standard for Inertial Sensor Terminology, IEEE Std 528-2001 (Reaffirmed 2007).

[3] Lawrence, A., "Modern Inertial Technology, Navigation, Guidance, and Control", Springer New York Pages:25-42, (1998).

[4] Wu, Z. C. , Wang, Z. F. and Ge, Y. ,"Gravity based online calibration for monolithic triaxial accelerometers' gain and offset drift", Intelligent Control and Automation, 2002. Proceedings of the 4th World Congress on (Volume 3), Pages:2171 – 2175 (2002).

[5] Li, Z., Li, X. and Wang, Y., "A calibration method for magnetic sensors and accelerometer in tilt-compensated digital compass", Electronic Measurement & Instruments, ICEMI '09. 9th International Conference 2009, Pages:2868 - 2871 (2009).

[6] Tuck, K., NXP Semiconductors, "Implementing Auto-Zero Calibration Technique for Accelerometers", AN3447 (Rev 0) (1 June 2016). https://www.nxp.com/files/sensors/doc/app_note/AN3447.pdf

[7] Analog Devices, ADXL335 Data Sheet (Rev. B) (1 June 2016). http://www.analog.com/en/products/mems/mems-accelerometers/adxl335.html

[8] Analog Devices, ADXL327 Data Sheet (Rev. 0) (1 June 2016). http://www.analog.com/en/products/mems/mems-accelerometers/adxl327.html

[9] STMicroelectronics, LIS344ALH Data Sheet (DS5671) (1 June 2016). http://www.st.com/content/st_com/en/products/mems-and-sensors/accelerometers/lis344alh.html

[10] InvenSense, MPU9255 Data Sheet (1 June 2016). https://www.invensense.com/products/motion-tracking/9-axis/mpu-9255-2/

[11] STMicroelectronics, "Tilt measurement using a low-g 3-axis accelerometer", AN3182 Application note (1 June 2016).http://www.st.com/content/ccc/resource/technical/document/application_note/8e/28/c0/ea/1f/ed/4e/48/CD00268887.pdf/files/CD00268887.pdf/jcr:content/translations/en.CD00268887.pdf