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The Low – Cost Accelerometer Calibration Algorithm Meets Accuracy Compared to High – Quality Accelerometer

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Abstract

At present, industrial accelerometers with measuring range lower than ± 0.3 m/s^2 on the market are scarce and expensive, not suitable for research projects as well as equipment applications in large quantities. The use of cheaper sensors requires a device to calibrate and check actual responsiveness. This article presents the calculation and design of the mechanical structure, and proposes the calibration algorithm to test and calibrate low – cost accelerometers for industrial use. This is an extremely necessary issue today.

Keywords: *Accelerometer, Calculation, Design, Calibration Algorithm, Mechanical Structure.*

1. Introduction

The accelerometer sensor is a device used to measure acceleration, acceleration, or vibration measurement of an object or a frame system, which is widely used in many fields: measuring vehicle acceleration and vibration on cars and machines; monitoring the health of devices; supervision of construction works and infrastructure; evenly oriented equipment; cranes and cranes move goods; etc.

Hongki Jo et al. [1] developed an accelerometer sensor board as a reference sensor to improve the ability to capture structural behavior in intelligent sensor networks. The SHM-H board with the Imote2 platform is proven to measure low-level vibrations around the truss structure with high efficiency. Denis Mougenot et al. [2] presented the actual expectations and achievements of the experimental microelectromechanical systems (MEMS) based accelerometers in the seismic field. Some of the highest channel count 3D seismic surveys are recorded by 3C MEMS accelerometers with over 90,000 channels, compatible with cable and wireless systems, established from land to transition zone and deep offshore. Laine, Jérôme, and Mougenot, Denis [3] have developed a new accelerometer based on a microelectromechanical system (MEMS) that can provide broadband (0 to 800 Hz) and highly accurate measurements of motions on the ground at a low level. Tests carried out underground can detect noise levels with low frequencies and weak signals in the seismic field. Narasimhan V. et al. [4] presented an overview of research and commercialization by discussing design options, sensor diagrams, and trends in micromechanical high-g accelerometers is typical, providing high accuracy of future seismic measurements. Lee, J.M. et al. [5] designed, fabricated, and tested an accelerometer sensor with a spring pad with a sensitivity of 34.6 μV/g, with high stability. In the article, the accelerometer is used in high-acceleration measurements. Li R-J et al. [6] proposed the design of a low-cost, high-sensitivity optical accelerometer that consists of three main components: a seismic mass, a leaf spring, and a sensor-based part, the quadruple optical sensor. The accelerometer sensor is tested with a sensitivity of 1.74 V $(m \times s^{-2})^{-1}$, accelerometer range 0.003 ÷ 7.29 $m \times s^{-2}$, and operating frequency range of 0.4 ÷ 12 Hz. This accelerometer is applied in vibration detection, low-frequency, low-amplitude dynamic response, monitoring, machine tool diagnostics, and structural oscillation. S. Gao et al. [7] proposed a high-resolution accelerometer prototype to reduce thermomechanical noise. The theoretical model based on the Gaussian beam theory and the tuning method based on the slit beam configuration improves the contrast ratio of order 0. Compared with the previous prototype, the test results of this paper show sound noise decreased from 0.9 mg/pHz to 137 ng/pHz, and apparent stability decreased from 0.35 mg to 3.1 μg. Qu, Ziqiang, et al. [8] introduced a susceptible optical microelectromechanical system acceleration sensor based on silicon-on-insulator (SOI) dual-sided micromachining technology, which can overcome these problems. The difficulty of integrating optical components and low-frequency suspension microstructures. In this paper, the sensitivity of the optical accelerometer is measured to be 100 $ng/Hz^{1/2}$, which is better than that of the previously published optical microelectromechanical system accelerometer.

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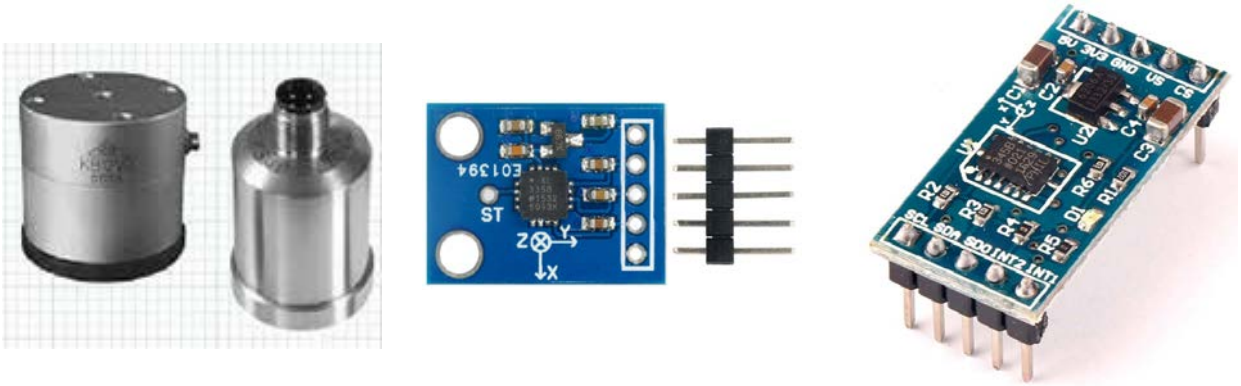
Nowadays, accelerometers have very popular applications, but industrial accelerometers on the market are very expensive; for example, the MMF KB12VD/01 accelerometer (Figure 1.a) costs from 2000 ÷ 3000 USD. There are also cheaper accelerometers like ADXL335 (Figure 1.b), ADXL345 (Figure 1.c), etc., but these types of sensors, although they give stable values, are different from industrial sensors and, if calibrated well, can be used in many applications that do not require high measurement accuracy. Therefore, to optimize the production cost while measuring the accelerometer, ensure the accuracy of the accelerometer is guaranteed to be within the allowable range for devices that need relative accuracy (errors about ± 0.3 m/s^2), then the low-cost accelerometer calibration into a usable sensor would be highly economical and meet a wide range of practical requirements.



a. MMF KB12VD/01 b. ADXL335 c. ADXL345

Fig. 1 Several types of accelerometer.

2. Dynamic diagram, the size of the operating range of the accelerometer correction mechanism – slider crank mechanism

The general principle for calibrating accelerometers is to use a device that produces a standard accelerometer. Then, install the accelerometer to be calibrated in the accelerometer, and determine the acceleration variation within the range to be calibrated. From there, compare the standard value and the reading from the accelerometer to calculate the value to be corrected.

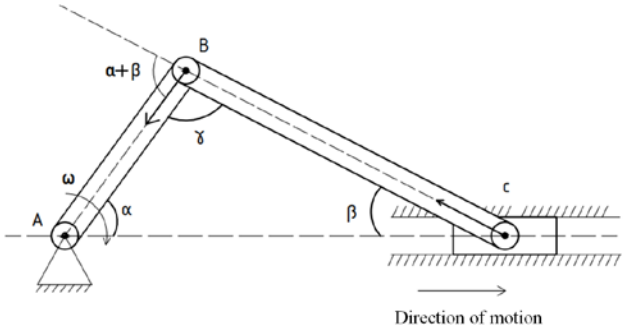


Fig. 2 Diagram of the slider – crank mechanism.

Many devices can fulfill the above principle. However, the principle of the flat four – link mechanism (shown in Figure 2) is simple and effective. Because this mechanism can use a servo motor located at the handwheel, with a standard and adjustable angular velocity, the stitch lengths can be precisely machined, which reduces the standard acceleration error

calculated from the mechanism. The accelerometer to be calibrated is located at the slider easily. The small size structure is suitable for the laboratory. This article will calibrate the accelerometer from g = 0 to g = 9.81 m/s^2.

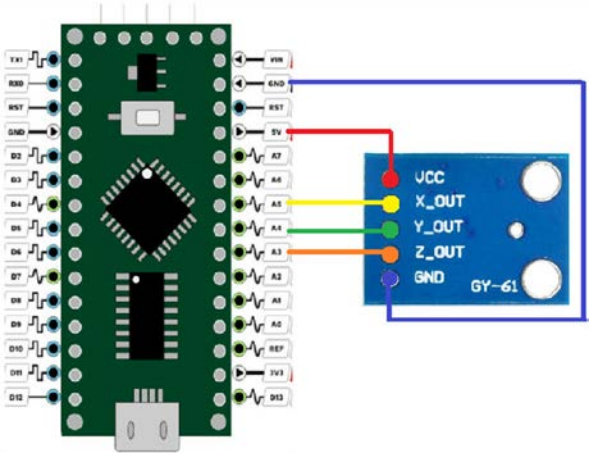


Fig. 3 Principle schematic of the calibration value storage connection with ADXL335.

3. Equipment used in the accelerometer correction mechanism

The mechanism uses the Panasonic MHMF082P1T – AC Servo motor (shown in Figure 4), speed controlled based on DRIVER MCDDT3520003 (shown in Figure 5), indirect drive through PX80N003SA_SERVO circular gearbox (shown in Figure 6). The XGT-44C-16-19 connecting shaft (shown in Figure 7) connects the gearbox shaft and main shaft, connecting to the crank. On the primary spindle use, two SNR_SUCPA205_0 bearings (shown in Figure 8). Combine with EGH25CA slider and slider to create the reciprocating movement of the mechanism. Use the ADXL335 sensor (shown in Figure 9), and the CH340 nano board (shown in Figure 10) mounted on the slide to calibrate the acceleration value and store this correction value.

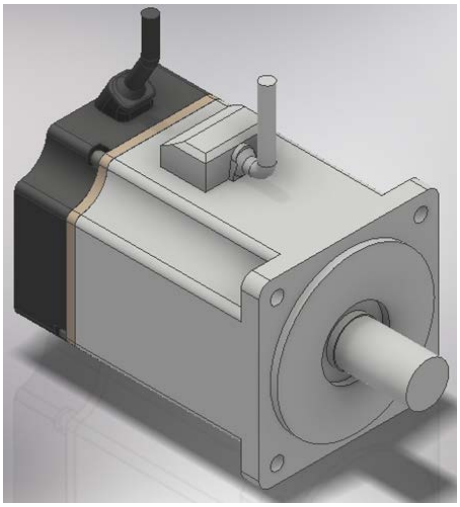


Fig. 4 The Panasonic MHMF082P1T – AC Servo motor.

Fig. 5 DRIVER MCDDT3520003.

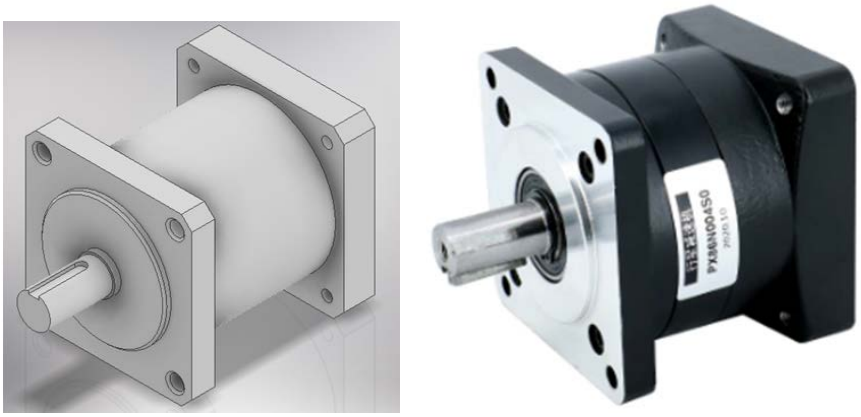


Fig. 6 PX80N003SA_SERVO circular gearbox.

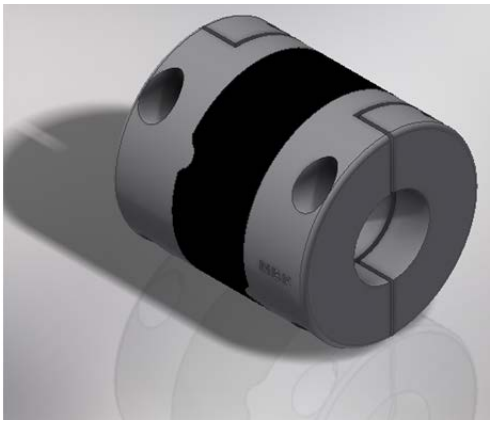


Fig. 7 The XGT-44C-16-19 connecting shaft.

Fig. 8 SNR_SUCPA205_0 bearing.

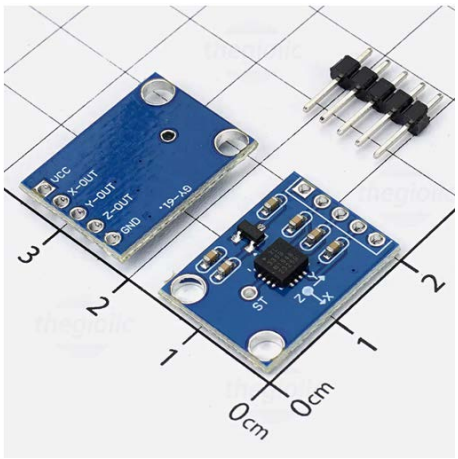


Fig. 9 The ADXL335 sensor.

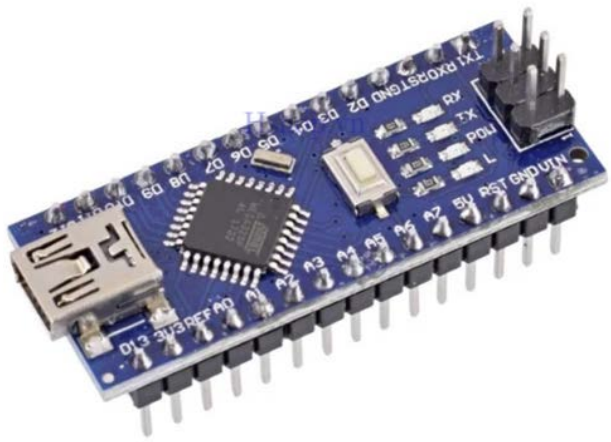


Fig. 10 The CH340 nano board.

4. Calculate the acceleration value according to the rotational speed of the motor and calibrate the accelerometer mounted on the slider

Acceleration of the mechanism shown in Figure 11.

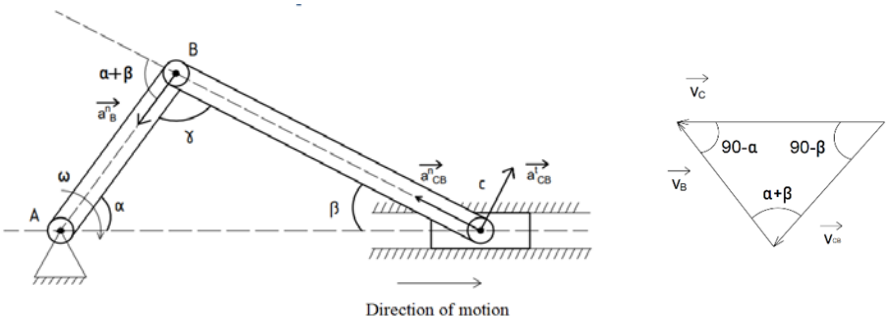


Fig. 11 The acceleration of the mechanism.

Set AB = a, BC = b, B is the pole.

$$\vec{a}_C = \vec{a}_B + \vec{a}_{CB} = \vec{a}_B^n + \vec{a}_{CB}^n + \vec{a}_{CB}^t \quad (1)$$

In the direction $\overrightarrow{CB}$:

$$a_C \cos\beta = a_B^n \cos(\alpha+\beta) + a_{CB}^n \quad (2)$$

$$\Rightarrow a_C = \frac{a_B^n \cos(\alpha+\beta) + a_{CB}^n}{\cos\beta} \quad (3)$$

$$\Rightarrow a_C = \frac{a \times \omega_{AB}^2 \cos(\alpha+\beta) + \dfrac{(a \times \omega_{AB} \sin(90-\alpha))^2}{b \sin(90-\beta)^2}}{\cos\beta} \quad (4)$$

$$\Rightarrow b = \frac{\left[a.\omega_{AB}.\sin(90-\alpha)\right]^2}{\left[a_c.\cos(\beta) - a.{\omega_{AB}}^2.\cos(\alpha+\beta)\right].\sin(90-\alpha)^2} \quad (5)$$

Select a_C from 0 to 9.81 m/s^2, and the angular velocity of the servo motor passed through the reducer ω_{AB} from 0 to 8.73 rad/s.

The AB crank should be as compact as possible. However, a = 90÷100 mm is required to process and assemble the structure.

Based on equation (5) to calculate b:

No.	a (mm)	b (mm)
1	90	208,5
2	91	218,8
3	92	229,7
4	93	241,3
5	94	256,4
6	**95**	**267**
7	96	280,6
8	97	295,5
9	98	311,4
10	99	328,5

Choosing a = 95 mm and b = 267 mm is the most reasonable when machining to ensure a compact size and required accuracy.

The motor rotates with a constant angular velocity ω_{AB} to calibrate the sensor's acceleration value. The slider acceleration (acceleration sensor mounting position) will vary in sinusoidal form and take the maximum of this acceleration value. The slider will have the greatest acceleration when at the farthest position of the handwheel; at this time, bar AB and BC are aligned.

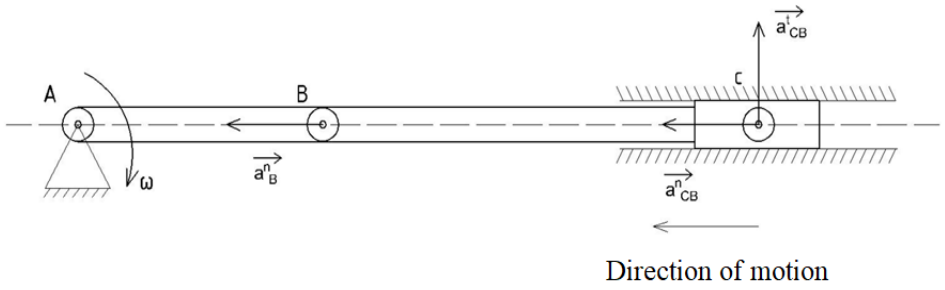


Fig. 12 The acceleration of the mechanism is at the farthest position of the handwheel

Replace a = 0.095 mm, b = 0.267 mm, and $\alpha = \beta = 0$ to Equation (4):

$$\Rightarrow a_C = 0.095 \times \omega_{AB}^2 + \frac{(0.095 \times \omega_{AB})^2}{0.267} \qquad (6)$$

Divide ω_{AB} into 60 equal intervals and the corresponding a_C value as follows:

No.	0	1	2	3	4	5	6	7	8	9	10	11
ω_{AB}	0	0.145	0.290	0.435	0.58	0.725	0.87	1.015	1.16	1.305	1.45	1.595
a_c	0	0.003	0.011	0.024	0.043	0.068	0.098	0.133	0.173	0.220	0.271	0.328

No.	12	13	14	15	16	17	18	19	20	21	22	23
ω_{AB}	1.74	1.885	2.03	2.175	2.32	2.465	2.61	2.755	2.9	3.045	3.19	3.335
a_c	0.391	0.459	0.532	0.611	0.695	0.784	0.879	0.980	1.085	1.197	1.313	1.435

No.	24	25	26	27	28	29	30	31	32	33	34	35
ω_{AB}	3.48	3.625	3.77	3.915	4.06	4.205	4.35	4.495	4.64	4.785	4.93	5.075
a_c	1.563	1.686	1.834	1.978	2.127	2.282	2.442	2.608	2.779	2.955	3.137	3.324

No.	36	37	38	39	40	41	42	43	44	45	46	47
ω_{AB}	5.22	5.365	5.51	5.655	5.8	5.945	6.06	6.235	6.38	6.525	6.67	6.815
a_c	3.517	3.715	3.918	4.127	4.342	4.561	4.787	5.017	5.253	5.495	5.742	5.994

No.	48	49	50	51	51	53	54	55	56	57	58	59
ω_{AB}	6.96	7.105	7.25	7.395	7.54	7.685	7.83	7.975	8.12	8.265	8.41	8.55
a_c	6.252	6.515	6.784	7.058	7.337	7.622	7.912	8.208	8.509	8.816	9.128	9.445

Above is the value of the slider's acceleration. The accelerometer value of the sensor installed on the slider will be calibrated to these values.

5. The acceleration value after calibrated

In this article, the ADXL355 sensor to be calibrated is installed on the slider. The reading values of this sensor when the mechanism is operating are a_{Cr0} to a_{Cr59} (these acceleration values are the max acceleration values corresponding to each angular velocity ω_{AB}).

Let Δ_{Cn} be the acceleration difference between the values a_{Cn} (the output acceleration value after calibrated) and a_{Crn} corresponding to the values ω_{ABn} :

$$\Delta_{Cn} = a_{Cn} - a_{Crn} \quad (7)$$

$$\Rightarrow a_{Cn} = a_{Crn} + \Delta_{Cn} \quad (8)$$

In each different position, there will be other Δ_{Cn} differences. The acceleration value Δ_{Cn} will be recorded in the EEPROM integrated with the ADXL 335 accelerometer.

The ADXL335 accelerometer calibration module (shown in Figure 13) consists of the ADXL335 sensor and one EEPROM storage, with accuracy ± 0.3 m/s^2.

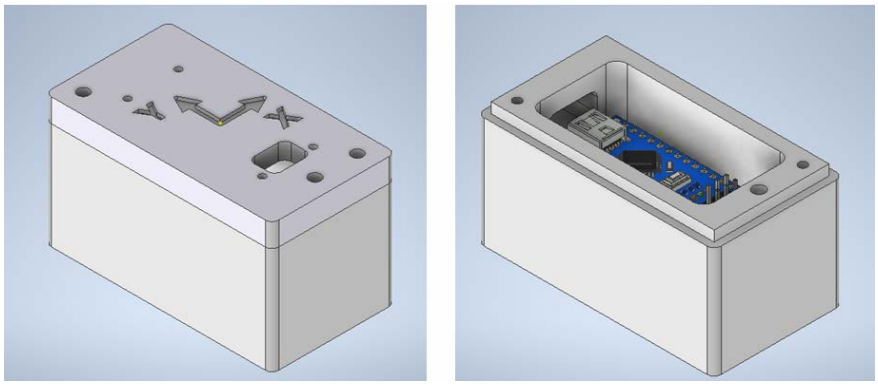


Fig. 13 The ADXL335 accelerometer calibration module.

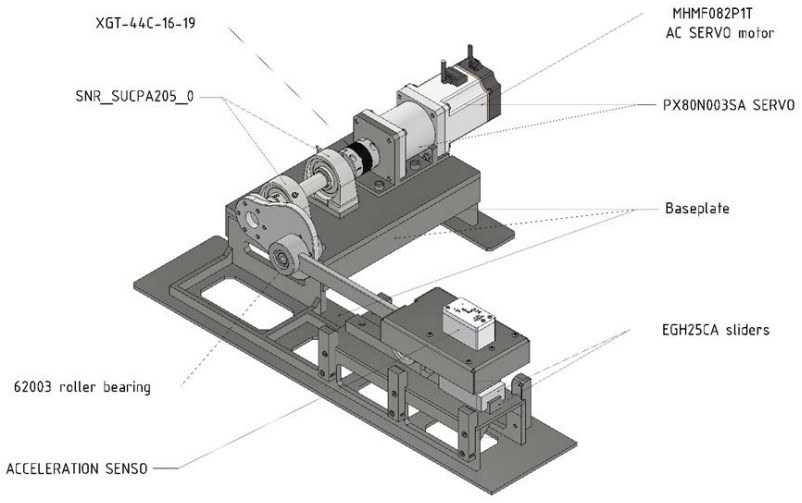


Fig. 14 The 3D model of the accelerometer calibration mechanism.

6. Conclusions

The article performs the computation and design of the mechanical structure and calibrates low – cost accelerometers to meet accuracy (with errors do not exceed $\pm$ 0.3 m/s^2) compared to high – quality accelerometers.

Besides, this article results show that this is calibrating with devices that do not need too high accuracy meets the technical requirements and brings high economic efficiency.

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