Application Note

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Calibration Algorithm Based on NSA(C)9260

AN-12-0026

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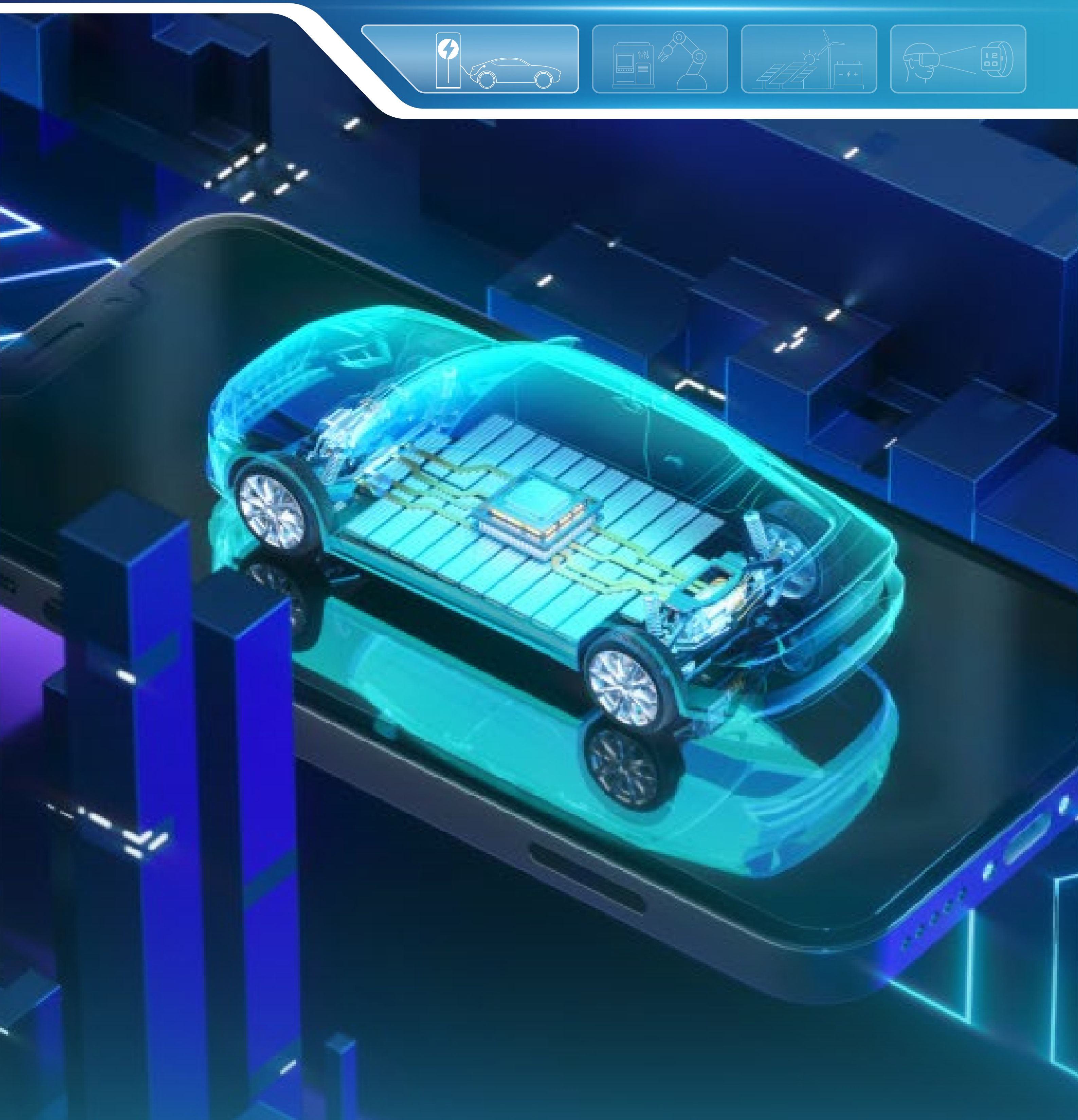

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ABSTRACT

This article mainly introduces the internal algorithm process of NSA(C)9260, from the collection of raw data to the final output of voltage data.

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1.Pin Configuration and Functions

NSA(C)9260 signal chain is illustrated in Figure 1.1. Sensor output signal will be amplified through analog front end and will be quantized by PADC into a 24-bit digital output. Internal temperature sensor or external temperature sensor output will be amplified through auxiliary temperature measurement channel and quantized by TADC into a 24-bit temperature digital output. These two digital outputs will be calibrated by a built-in MCU and output to DAC to generate final analog voltage or current outputs. Calibration algorithm embed-ed in MCU, and corresponding calibration coefficients are stored in one 64-byte EEPROM. Calibration algorithm can be divided into ADC calibration (ADC CAL), sensor calibration (SENSOR_CAL), range ratio adjustment, and DAC calibration (DAC CAL). ADC calibration is to calibrate zero point and sensitivity of PADC output and TADC output. Sensor calibration is to calibrate sensor offset, sensitivity, non-linearity, and temperature drift of offset and sensitivity. Range ratio adjustment supports user to modify the product's range after module calibration is completed. DAC calibration is to calibrate zero point and sensitivity deviation of the analog output.

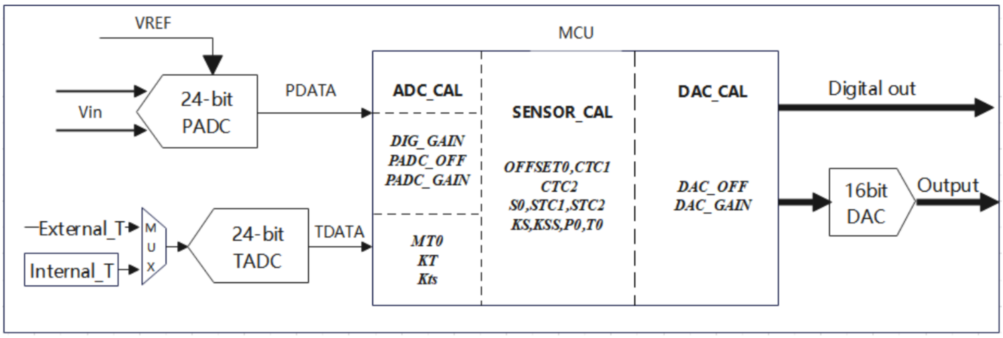

Figure1.1 NSA(C)9260 SIGNAL CHAIN

2.Data Normalization

In order to unify the data format and unit during the calibration, the output data of PADC and TADC, input data of DAC must be normalized. The normalized data is the ratio between the physical quantity and the full scale. For example, the normalized data of PADC data $PDATA_{RAW}$ is showed below:

$$PDATA_{RAW} = \frac{Vin * GAIN\_P}{VREF} = \frac{PDATA[23:0]}{2^{23}}$$

Symbol	Description
Vin	Voltage signal of input (V)
GAIN_P	Amplify factor of PGA
VREF	Reference voltage of ADC
ADC [23:0]	Output code of ADC, 24 bit complement code, PDATA [23] is sign bit, range is -2^23 to 2^23-1

The normalized data of DAC input is showed below:

$$\mathrm{DAC\_DATA} = \frac{\mathrm{DACOUT}}{\mathrm{DACFS}} = \frac{\mathrm{DAC\_DATA}[15:0]}{2^{16}}$$

Symbol	Description
DACOUT	Analog voltage or current output
DACFS	Full scale of DAC output
DAC_DATA [15:0]	Input code of DAC, unsigned, range is 0 to 2^16

3.Temperature Channel TADC Calibration

NSA(C)9260 support two temperature measurement modes, internal temperature sensor mode and external temperature sensor mode.

3.1.Internal temperature sensor mode

NSA(C)9260 internal temperature sensor is calibrated before sent out, and the calibration coefficient (MT0, KT) is saved in the register. If the system use internal temperature sensor, please don't modify the MT0 and KT register data. The temperature data can be read from TDATA register, the data format is

$$\mathrm{T}_{int} = \mathrm{TDATA}_{CAL} + 25℃$$

The 25℃ offset can support the output of temperature up to 153℃

3.2.External temperature sensor mode

The calibrated data can be read from register TDATA when using external temperature sensor. The output of TADC is TDATARAW, and the calibration formula shows below:

$$TDATA_{CAL} = T0 + (TDATA_{RAW} - MT0) * KT * [1 + KTS * (TDATA_{RAW} - MT0) * KT] * 128$$

The calibrated data format of external temperature sensor is recommended to set as below:

$$T_{ext} = TDATA_{CAL} + 25℃$$

T_{ext} is calibrated temperature data.
The parameter description of the formula is showed below:

Symbol	Description	Range	Default value	Data format
T0	Reference temperature, default is 0	(-128,128)	0	8-bit sign
$TDATA_{CAL}$	Calibrated temperature, saved at TDATA	(-128,128)	---	24-bit sign
$TDATA_{RAW}$	Raw data of TADC, saved at register TDATA.	(-1,1)	---	24-bit sign
MT0	Offset calibration coefficient of temperature sensor	(-1,1)	0	16-bit sign
KT	Full scale calibration coefficient of temperature sensor	(-8,8)	0	16-bit sign
KTS	Second-order nonlinearity coefficient of temperature sensor	(-1,1)	0	8-bit sign

4.PADC Calibration

PADC calibration is to calibrate offset and full scale of main signal channel (P channel).

$$PDATA_{CAL1} = (PDATA_{RAW} - PADC\_OFF) * (1 + PADC\_GAIN) * DIG\_GAIN$$

Symbol	Description	Range	Default value	Data format
$PDATA_{CAL1}$	Intermediate variable, output of PADC calibration	(-2,2)	---	---
PADC_OFF	Offset calibration coefficient of P channel	(-1,1)	0	24-bit sign
PADC_GAIN	Full scale calibration coefficient of P channel	(-0.5,0.5)	0	16-bit sign
DIG_GAIN	Digital gain of P channel	1,2,4,8	1	2-bit

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4.1.Sensor calibration

NSA(C)9260 can regulate offset and full scale of sensor. The second-order temperature coefficient of offset and full scale can be calibrated. Meanwhile, third-order nonlinearity coefficient of sensor can be calibrated.

$$\mathrm{OFFSET} = \mathrm{OFFSET0} + \mathrm{CTC1} * (\mathrm{TDATA}_{CAL} - \mathrm{T0}) + \mathrm{CTC2} * (\mathrm{TDATA}_{CAL} - \mathrm{T0})^2$$

$$\mathrm{S} = \mathrm{S0} * (1 + \mathrm{STC1} * (\mathrm{TDATA}_{CAL} - \mathrm{T0}) + \mathrm{STC2} * (\mathrm{TDATA}_{CAL} - \mathrm{T0})^2)$$

$$\mathrm{P_{NL}} = (\mathrm{PDATA_{CAL1}} - \mathrm{OFFSET}) * \mathrm{S}$$

$$\mathrm{PDATA_{CAL2}} = \mathrm{P_{NL}} + \mathrm{KS} * \mathrm{P_{NL}^2} + \mathrm{KSS} * \mathrm{P_{NL}^3} + P0$$

Symbol	Description	Range	Default value	Data format
$\mathrm{PDATA_{CAL2}}$	Intermediate variable, the data after linearity calibration	(-2,2)	---	---
OFFSET0	Offset calibration coefficient of sensor	(-1,1)	0	16-bit sign
CTC1	First-order temperature coefficient of sensor offset	(-0.00781,0.00781)	0	16-bit sign
CTC2	Second-order temperature coefficient of sensor offset	(-6.1e-5,6.1e-5)	0	16-bit sign
S0	Sensor sensitivity temperature coefficient	(0,2)	0	16-bit unsigned
STC1	First-order temperature coefficient of sensor sensitivity	(-0.00781,0.00781)	0	16-bit sign
STC2	Second -order temperature coefficient of sensor sensitivity	(-6.1e-5,6.1e-5)	0	16-bit sign
KS	Sensor second-order nonlinearity coefficient	(-1,1)	0	16-bit sign
KSS	Sensor third-order nonlinearity coefficient	(-0.5,0.5)	0	16-bit sign
P0	Nonlinearity calibration reference pressure value	(-1,1)	0	8-bit sign

For temperature sensor application such as RTD temperature measurement, it only needs the main channel, so the temperature calibration coefficient CTC1, CTC2, STC1, STC2 can be set to 0, so the calibration formula can be simplified as below:

$$\mathrm{P_{NL}} = (\mathrm{PDATA_{CAL1}} - \mathrm{OFFSET0}) * \mathrm{S0}$$

$$\mathrm{PDATA_{CAL2}} = \mathrm{P_{NL}} + \mathrm{KS} * \mathrm{P_{NL}^2} + \mathrm{KSS} * \mathrm{P_{NL}^3} + P0$$

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5.Range Adjustment

The data after sensor calibration will be calculated using below formula, the result PDATACAL will be saved into register PADTA. The range adjustment coefficient SCALE_OFF and SCALE_S are used for range override easily. For the product which range will adjustment in the future, recommend to set SCALE_OFF to 0, SCALE_S to 1, and use the maximum range to calibrate during initial calibration. Later, if the product need range adjustment, only need to adjust these two coefficients.

$$PDATA_{CAL} = (PDATA_{CAL2} - SCALE\_OFF) * SCALE\_S$$

Symbol	Description	Range	Default value	Data format
$PDATA_{CAL}$	Digital output after calibration	(-1,1)	---	24-bit sign
SCALE_OFF	Offset calibration	(-1,1)	0	24-bit sign
SCALE_S	Full scale calibration	(0,256)	0	24-bit unsigned

Take a 4~20mA output pressure transmitter as an example, the initial calibration pressure range is LP0～HP0, and DAC is calibrated, then the relationship between PDATA and output current is ILOOP=24mA*PDATA, LP0 corresponding PDATA digital output is 1/6, HP0 corresponding PDATA digital output is 5/6. Now the range will be adjusted to LP1～HP1, this means to adjust the coefficients SCALE_OFF and SCALE_S, then the pressure point LP1 and HP1 corresponding PDATA digital output is 1/6 and 5/6. Suppose the range adjustment coefficient is $SCALE\_OFF_{old}$ and $SCALE\_S_{old}$ at present. Then the new range adjustment coefficients can be calculated using the formula below:

$$SCALE\_OFF_{new} = \frac{5LP1 - HP1 - 5LP0 + HP0}{6SCALE\_S_{old} * (HP0 - LP0)} + SCALE\_OFF_{old}$$

$$SCALE\_S_{new} = \frac{HP0 - LP0}{HP1 - LP1} SCALE\_S_{old}$$

For example, if the initial range of a 4~20mA pressure transmitter is 0~100kPa, SCALE_OFF is 0, and SCALE_S is 1. In order to adjust range to 0～50kPa, only need to adjust SCALE_OFF to 1/12 and SCALE_S to 2.

6.DAC Calibration

NSA(C)9260 use DAC_OFF, DAC_GAIN to calibrate the offset and full scale of analog voltage or current output. The formula is showed below, DAC_DATA (positive value) is 16-bit input of DAC. After DAC calibration, the error of analog output is reduced, so the analog output can be calculated correctly using PDATACAL directly. Owe to the low temperature drift of internal reference voltage, only need to calibrate DAC once at room temperature. The temperature calibration coefficients of the sensor will be calibrated at the digital output.

$$\mathrm{DAC\_DATA} = (\mathrm{PDATA_{CAL}} - \mathrm{DAC\_OFF}) * (1 + \mathrm{DAC\_GAIN})$$

Symbol	Description	Range	Default value	Data format
DAC_DATA	Calibrated input of DAC	(0,1)	0	16-bit unsigned
DAC_OFF	Offset calibration coefficient of DAC	(-1,1)	0	16-bit sign
DAC_GAIN	Full scale calibration coefficient of DAC	(-0.5,0.5)	0	16-bit sign

7.Sensor Calibration Process of Digital Output

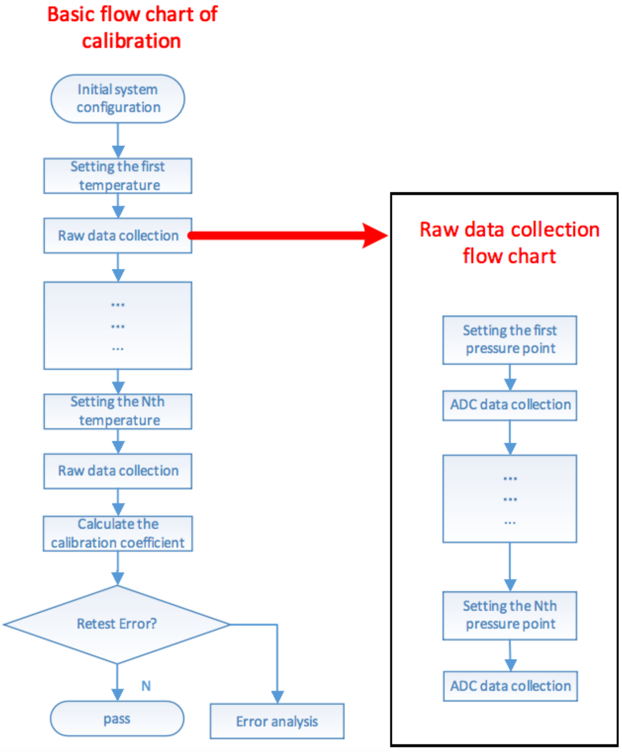

Figure 7.1 Sensor calibration process

Table 7.1： Relationship between calibration coefficients and the least data collection point

	T1				T2				T3			
OFFSET0、S0	P1	P2	--	--	--	--	--	--	--	--	--	--
OFFSET0、S0、KS	P1	P2	P3	--	--	--	--	--	--	--	--	--
OFFSET0、S0、KS、KSS	P1	P2	P3	P4	--	--	--	--	--	--	--	--
OFFSET0、S0、CTC1、STC1	P1	P2	--	--	P1	P2	--	--	--	--	--	--
OFFSET0、S0、CTC1、STC1、KS	P1	P2	P3	--	P1	P2	--	--	--	--	--	--
OFFSET0、S0、CTC1、STC1、KS、KSS	P1	P2	P3	P4	P1	P2	--	--	--	--	--	--
OFFSET0、S0、CTC1、CTC2、STC1、STC2	P1	P2	--	--	P1	P2	--	--	P1	P2	--	--
OFFSET0、S0、CTC1、CTC2、STC1、STC2、KS	P1	--	P3	--	P1	P2	P3	--	P1	--	P3	--
OFFSET0、S0、CTC1、CTC2、STC1、STC2、KS、KSS	P1	--	--	P4	P1	P2	P3	P4	P1	--	--	P4

8.Calibration DLL Description

NOVOSENSE offer the calibration calculation algorithm which is DLL format. User can use the DLL to calculate the calibration coefficients according to the collected raw data and target value. The input and output parameter formats of the DLL are showed below:

8.1.Input parameters:

PData： 8-bit double- precision array, the normalized data of calibration target value
TData： 8-bit double- precision array, temperature value of sensor calibration(℃)
RData： 8-bit double- precision array, the normalized data of raw data
Tstand： T0 in the step 5, reference temperature.
Pstand： P0 in the step 5, nonlinearity calibration reference pressure value.
Psize： Rdata array size.
CalMode：

- 2P1T mode is 1;
- 3P1T mode is 2;
- 4P1T mode is 3;
- 2P2T mode is 4;
- 3P2T mode is 5;
- 4P2T mode is 6;
- 2P3T mode is 7;
- 3P3T mode is 8;
- 4P3T mode is 9;
- 2P3T segmental calibration mode is 10;
- 3P3 segmental calibration mode is 11;
- 4P3T segmental calibration mode is 12;

8.2.Output parameters:

8-bit double- precision array, the array parameters in the order is OFFSET0, CTC1, CTC2, S0, STC1, STC2, KS and KSS.

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9.Revision History

Revision	Description	Author	Date
1.0	Initial version	Feifei Sun	16/6/2023