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LINEARIZATION TECHNIQUES OF SENSOR: A COMPARATIVE STUDY

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Abstract

A comparative analysis of different linearization Techniques for sensor signals is presented. Several solutions in the analog, and digital domains are considered. The analysis will help designers to choose the linearization technique best suited for a given application

Keywords: Sensors; Transducers; linearization; Analog Sensors; Digital Sensors; Sensor Linearization

I. Introduction

The majority of the Sensors show nonlinear transfer characteristics, requiring linearization. Typical nonlinear characteristics are exponential, sinusoidal, or tangential. The choice of an adequate linearization method is critical for the overall performance of the system

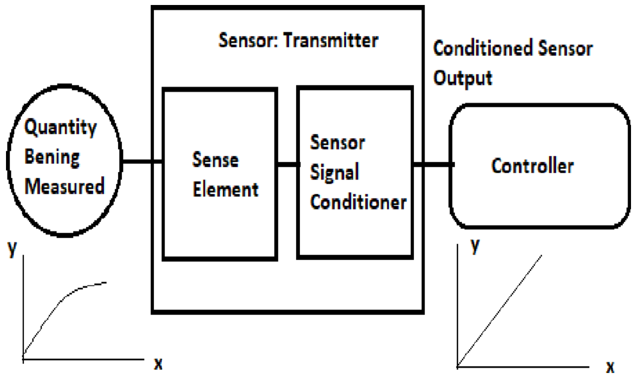

Fig 1. Sensor Linearization Process Overflow

Figure. 1 show that the physical quantity being measured is fed through input, the output of the sensing element is taken, and the output of the sensor signal conditioner is processed. The sensor signal conditioner processes the sense element output for non-idealities such as nonlinearities, temperature variation, and dynamic response. In this paper, the discussion is made on the processing of the sensor element output for a decrease in nonlinearity. Several techniques have been proposed to linearize sensor characteristics. They can be classified into three groups: Analog, Digital, and Mixed-mode techniques. In the first case, analog signal processing by passive or active elements is employed to linearize the sensor output. The analog block achieving such linearization has a characteristic that approximates the inverse of that of the sensor. Thus, various types of transistor amplifiers are widely employed for interfacing sensors featuring exponential characteristics like thermistors. The second group of techniques consists in the digital linearization carried out after the A/D conversion of the sensor output. A common technique in this group is the use of a ROM look-up table. The third group of techniques achieves linearization in the A/D conversion step, employing a nonlinear A/D converter that has a nonlinear characteristic such that the nonlinearity of the sensor output is removed; this way, A/D conversion, and linearization are performed jointly using a single physical unit. This paper makes a comparative analysis of these Linearization techniques

II. Analog Linearization Techniques

The use of analog circuits with passive and/or active Components to linearize sensor characteristics is the oldest and most intelligent approach. They are widely used for thermistors. The first proposals often employ a transistor amplifier, where a sensor is placed in the input of the Amplifier circuit. Another very popular technique is using along with the thermistor a passive resistor to excite it by a voltage source. This way, the current flowing through it can be made proportional to absolute temperature. Alternatively, astable or monostable multivibrator bridges can be used. Another technique is the use of temperature-to-frequency converters based on a single astable multivibrator. A fourth method, also very useful for other sensors with exponential characteristics, is the use of a logarithmic amplifier based on a diode. Several nonlinear analog circuits like multipliers or dividers have been employed to linearize second-

Table: 1 Comparative study on Analog Linearizers

Linearization technique name	Reference	Order of linearity
Diode, Logarithmic amplifier Linearizer	[XV]	0.2mv /^{0}C
Transistor Amplifier Linearizer	[X]	0.1mv /^{0}C
Serial resistive load divider linearizer	[VIII]	0.3mv /^{0}C
Segment wise Linearizer	[I]	0.2mv /^{0}C

order and higher-order sensor models. Many other less common methods have been proposed based on nonlinear analog circuits, like the use of neural networks or radial basis function networks. A simple analog linearization approach readily found in commercial interfaces for bridge sensors is based on the variation of the bridge bias voltage or current according to the output signal using feedback loops. The following table shows a comparative study between four of the common Linearization techniques.

III. Digital Linearization Techniques

The analog methods discussed here are complicated and involve precision components for implementation. The precision in these systems primarily depends upon the number of segments that are implemented. The more the number of segments more will be the accuracy. The design of such a circuit requires several precession passive and active components along with accurate trimming of breakpoints. This makes the circuit implementation a difficult task. Apart from this they also have the following drawbacks:

- Design complexity increases with the number of segments
- Adjustment of Break-point is tedious and time-consuming
- Dependence of the components on temperature and other operating parameters shifts the calibration.

With the dominance of digital VLSI circuits and digital signal processing, linearization techniques in the digital domain are nowadays the most used ones, particularly when high performance is demanded. Such techniques achieve as much accuracy as required by the designer, at the expense of more circuit complexity and/or more processing time. Another typical benefit is the programmability of the linearization circuit or algorithm, which eases the implementation of general-purpose sensor interfaces able to process signals from different kinds of sensors. These universal interfaces are becoming very common in the industry due to their wider market.

In this paper we also present a comparative analysis of these Digital Linearization techniques:

Table 2: Comparative study on DIGITAL Linearizers

Linearization technique name	Reference	Order of linearity
Point to Point Linearization	[VI]	0.5mv /^{0}C
Look up Table Based Linearization	[IX]	0.5mv /^{0}C
Microcontroller Based Linearization	[XI]	0.2mv /^{0}C
VLSI and FPGA Based Linearization	[III]	0.4mv /^{0}C

IV. Mixed Signal Linearization Techniques

Mixed signal linearization is a combination of both analog and digital methods to produce far more superiorly linearized signals when hardware models are concerned. The heart of any mixed signal linearizer is an ADC which is the connector between the analog and digital parts of the system. The basic idea of a mixed signal method is described below.

It is possible to perform linearization and A/D conversion in the same physical block, using a nonlinear ADC whose conversion characteristic is ideally matched to the inverse of the sensor characteristic. Such a nonlinear A/D conversion gets the best of each bit of resolution or, stated differently, requires the minimum number of bits for achieving a given resolution. Several approaches for the implementation of a nonlinear A/D conversion exist. A well-known method is based on the ratio metric property of most A/D converters. An external ratio metric reference voltage that is made dependent on the input voltage (typically by a simple resistive divider) is employed to achieve the required nonlinearity in the A/D conversion. The digital output voltage corresponds to the ratio of the input voltage to this input-dependent reference voltage. The resulting ADC can be regarded as an analog divider with digital output. Although this technique is simple, the correction of sensor nonlinearity is modest, much lower than that achieved by digital linearization techniques. The reason for the limited accuracy is that it is not possible to exactly implement the ideal A/D conversion characteristic, i.e., the inverse of the sensor characteristic. An alternative approach that achieves better accuracy is the implementation of ADCs whose conversion characteristic is a PWL approximation to the inverse of the sensor characteristic. The circuit can be equivalently seen as a PWL analog linearization circuit followed by a linear ADC. If the number and size of the PWL segments are properly chosen (i.e., low RMS error with regard to the ideal A/D characteristic is achieved) high accuracy can be obtained by a relatively simple circuit. The following circuit illustrates design issues of this kind of A/D converter.

A basic mixed signal sensor linearizer contains both analog and digital components. At the initial stage, basic linearization is done by the voltage divider circuit. The output generated from the two circuits is already linearized by the analog method and is sampled and held before feeding to the next segment. Sample and hold circuit match the speed of analog segment with the digital segment followed. Generated signal is then given to the digital linearizer which first shapes the signal and feeds it to the memory-based linearizer. Based on the digital conversion of an analog signal, the look-up table present in the last stage of the circuit produces the final linear output. Though the circuit produces superior output in comparison with the Analog or digital linearization techniques, it is much more complicated to synchronize two of the different systems.

Table 3: Comparative study on Mixed Signal Linearizers

Linearization technique name	Reference	Order of linearity
Mixed Signal Linearizer	[II]	0.01v /^{0}C

V. Comparison and Conclusion

Nine different groups of linearization techniques for sensor signals have been presented. Depending on the requirements of the application, one of these techniques may be superior to the others.

Analog linearization techniques are in general the simpler ones and can have a low cost in terms of silicon area and power consumption. Their main drawbacks are sensitivity to environmental conditions (mainly temperature), lack of flexibility when a different kind of sensor is employed, and that accuracy is high typically only in a small input range. Hence, they are usually the preferred choice in low-cost, low-performance applications where the linearized output is required in analog form.

Digital techniques offer more flexibility and accuracy. They can be implemented in general-purpose or dedicated hardware, which is programmed to achieve the required function. However, the potentially high accuracy obtained has a penalty in terms of silicon area and/or processing time. However, due to the advances in digital VLSI circuits, the processing overload of linearization is becoming manageable unless in particular applications where low power or low cost are key factors.

Mixed-signal techniques are particularly suited to applications where the sensor signal has to be converted to digital form and where the signal processing overhead of digital linearization in terms of silicon area, processing time, and power consumption, need to be minimized. This may be the case, for instance, in low-cost integrated sensor interfaces, where reasonable performance must be obtained at the minimum silicon cost.

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Conflicts of Interest:

The authors declare that they have no conflicts of interest to report regarding the present study.

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