A NOVEL DATA COMPRESSION TECHNIQUE FOR 4-20 MA CURRENT LOOP TRANSMITTERS

S. J. Azhari and H. Kaabi

Electronic Research Center, Iran University of Science and Technology (I.U.S.T)
Tehran, Iran, erc@iust.ac.ir

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Abstract This paper presents a new data compression method for current loop transmitters. In this method, the 4-20 mA current domain is divided into some equal pieces that are used for distinct data domain with a constant relative resolution, resulting in widening the signal span. This technique eliminated the need for high resolution ADC's or DAC's in communication of 4-20mA current loop signals. Furthermore, because of high amplitude of current steps the sensitivity of transmitter and receiver to noise and interference is reduced. As this is a software-based technique, there is no need to change the structure of the intelligent transmitters.

Key Words Current Transmitters, Data Compression, Intelligent Transmitters, Data Decoding.

چکیده این مقاله روشی جدید برای فشرده سازی اطلاعات در انتقال دهنده ابزاردقیق جریانی هوشمند را ارائه می‌کند. در این روش، بازه 4-20mA بر حسب نیاز به چند قسمت مساوی تقسیم شده و از هر کدام از آنها برای ارسال محدوده مشخصی از اطلاعات اندازه‌گیری شده با قدرت تفکیک نسبی ثابت استفاده می‌شود. این امر امکان ارسال سیگنال با فراخنای چندین دهه را که تا کنون غیر ممکن می‌نمود بر روی خط انتقال سیگنال 4-20mA فراهم می‌کند. در این روش به مبدل‌های آ–د و د–آ با قدرت تفکیک بالا نیازی نیست، از این رو بدلیل بزرگ بودن پله‌های ارسال سیگنال حساسیت انتقال دهنده و گیرنده آن نسبت به نویز و تداخل کاهش یافته است. بدلیل نرم‌افزاری بودن این روش، نیازی به تغییر ساختار انتقال دهندهای هوشمند فعلی وجود ندارد و تنها اعمال تغییرات برای اصلاح آنها کفایت می‌کند.

INTRODUCTION

Nowadays, intelligent transmitters play a main role in instrumentation and other related industrial applications. The enhanced data processing ability in conjunction with simplicity in installation and maintenance makes them a unique system for transmission of processing signals [1].

New ADC's[1] have large resolutions [2-6] that enable them to process signals with high resolution. However, unfortunately, in industrial applications, due to high levels of noise and interference, this capability becomes useless. Furthermore, as shown in Figure 1, because of the constant span of 4-20mA transmitting signal, detection of low level signal steps in the presence of interfering signals is a serious difficulty. This is due to the reduction of total S/N ratio, which makes detection of signals with high resolution impossible. Thus, validity of qualitative status in relation 1 is necessary:

$$i_E = i_{\text{int}} + \sqrt{\bar{i}_n^2} << \frac{Span}{2^N} \quad (1)$$

Where "N" is the resolution[2] of received or transmitted signal, "$\bar{i}_n$" is current noise and "i_E" is the total error current.

In instrumentation, considering all aspects

[1] Employing ΣΔ conversion techniques

[2] In terms of bits

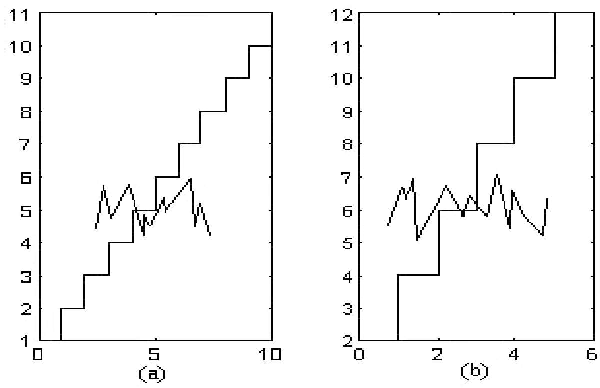

Figure 1. (a) Small steps and (b) Large steps.

(such as intrinsic S/N of ADCs & DACs and economy) the resolution of 12 bits is generally taken as the best value [7]. On the other hand, in general, there is a reverse relation between the span width and the resolution. It means that, with the same hardware and supply currents, the wider the span, the lower the resolution. Thus, designers have to tolerate a span-resolution trade off, design a more complicated hardware, and/or use higher supply signals [8]. This paper presents a method to overcome the problem as follows:

At first, the transmitted signal is compressed or merged before sending, which could then be transmitted by fewer bits using a conventional DAC (with a maximum resolution of 12-bits). At the destination, the received 4-20mA signal will be converted to a low resolution numerical value (max 12-bits), which could then be decoded to initial value with respect to transmitter signal (see Figures 2 a,b).

Nowadays there are countless techniques for compression or expansion of data in telephone communications [9-11], television broadcasting [12-13] and mass storage and processing of images [14-16].

The main goal in these applications is the reduction of bandwidth or massive data volume of speech or video signals needed for storage or transmission. In instrumentation applications, due to massive volume of data, analog commanders [12] or high-speed digital processors [17-18] are needed.

On the other hand, due to special nature of process signals that are too slow and thus have limited bandwidth, application of above mentioned devices are not reasonable. Thus, simple algorithms proportional to the nature of process signals must be innovated to be executed by simple and slow processors existing in intelligent transmitters.

BASIC CONCEPTS

The variable to be measured can be sized with respect to the span by units. On the other hand, for displaying analog variables (by digital displays), ADCs should convert them to digital data, gaining the ability of being monitored by digital displays. In this conversion, the relationship between relative resolution[3] and span can be shown by Relation 2 (see Figure 3):

$$R = \frac{S}{10^{n}} \tag{2}$$

In this relation, "n" is the number of displayed digits, "R" is relative resolution and "S" represents the span. In various applications, sufficient number of digits could be chosen according to required accuracy.

Although very high-resolution converters (ADC or DAC) are available, in practice for each measuring range, the meaningful digits are fixed. In other words, absolute resolution will vary in such a way that "R" remains constant for different measuring ranges.

This property can be employed to merge (compress) data. In this procedure, for "n", the most significant digits of measured variable will extracted and the least significant digits will be omitted. Figure 4, shows this procedure for a one-digit variable. Thus, for each measuring range the resolution is 10% of the related span.

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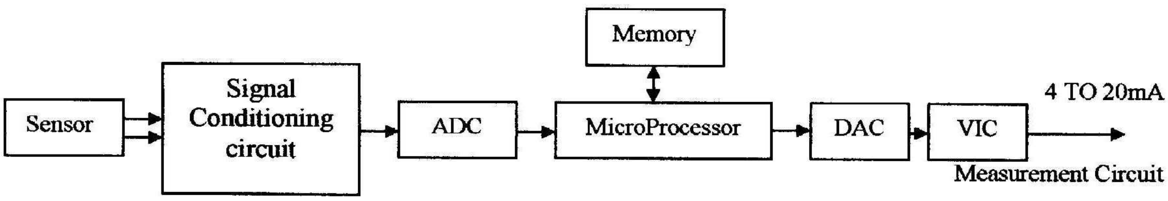
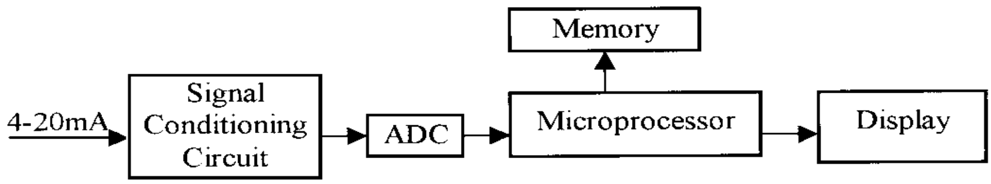
[3] Unit change



(a)



(b)

Figure.2. (a) Transmitter block diagram and (b) Display unit block diagram.

This procedure can be implemented using the algorithm shown in flowchart of Figure.5. In this procedure, for the smallest range, a unit change in input variable will produce a unit change in output. While in the next upper range, each 10-unit change in input will produce a unit change in output. This relationship is valid for all successive ranges. In Figure.5 "x" is the input variable, "Y" is the compressed output variable and "n" is the most significant digits needed for displaying the variable "x".

The "m" digit number (variable x) is expressed by (3):

$$x = 10^m \cdot a_m + 10^{m-1} \cdot a_{m-1} + \cdots + a_0 \qquad (3)$$

In which "a_0-a_m" are integer values between 0-9.

For "n", the most significant digits of "x"[4] can be extracted simply by using the proposed algorithm. It can be proved that output variable Y can be calculated directly from (4) or (5):

$$x < 10^n \Rightarrow Y = x = 10^m \cdot a_m + 10^{m-1} \cdot a_{m-1} + \cdots + a_0$$
(4)

$$x \geq 10^n \Rightarrow Y = p \cdot 10^n + \left[(x - \sum_{k=0}^{p-1} 10^{k+n}) / 10^p \right]$$
(5)

Where "p" is a positive integer that satisfies in (6):

$$\sum_{k=0}^{p-1} 10^{k+n} \leq x < \sum_{k=0}^{p} 10^{k+n} \qquad (6)$$

This technique reduces the volume of output variable being justified by relation (7):

$$Y \leq (p+1) \cdot 10^n << x \qquad (7)$$

After compression, the variable will be converted to an analog form by a DAC, which will then be changed to a 4-20mA signal and transferred to the destination.

[4] Variable Y

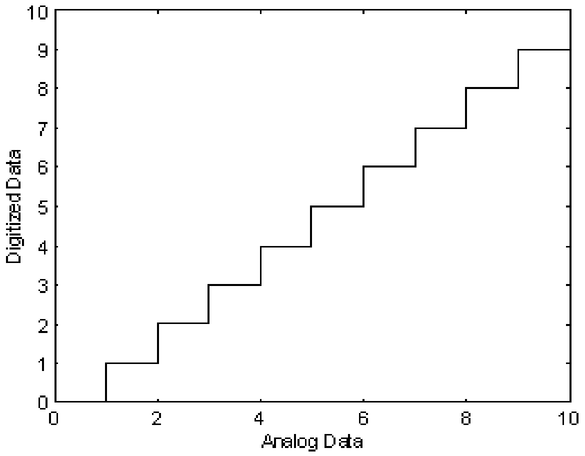


Figure3. Relationship between span and resolution.

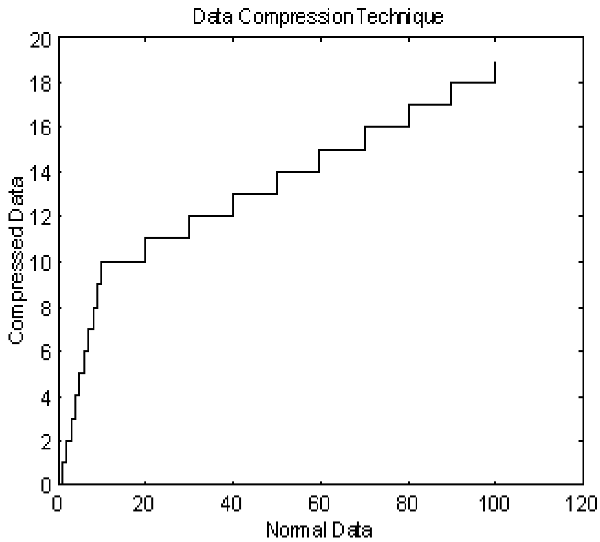


Figure 4. Graphical representation of compression technique.

The display unit (Figure 2b) will extract the compressed signal by an ADC. Then, an expansion algorithm, as shown in Figure 6, is employed to recover the n most significant digits of the primary variable "x".

In this algorithm, "Y" and "X" denote the compressed and expanded variables respectively. It is shown that "X" includes the "n" most significant digits of "x", thus:

$$X=(Y-p.10^{n}).10^{p}+\sum_{k=0}^{p-1}10^{k+n} \qquad (8)$$

Hence

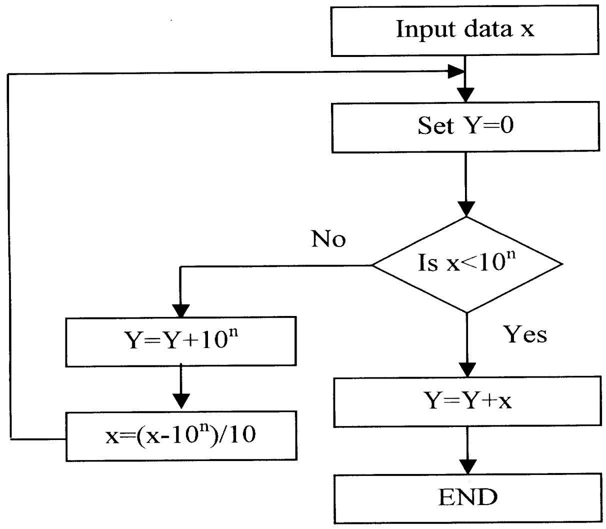


Figure 5. Proposed algorithm.

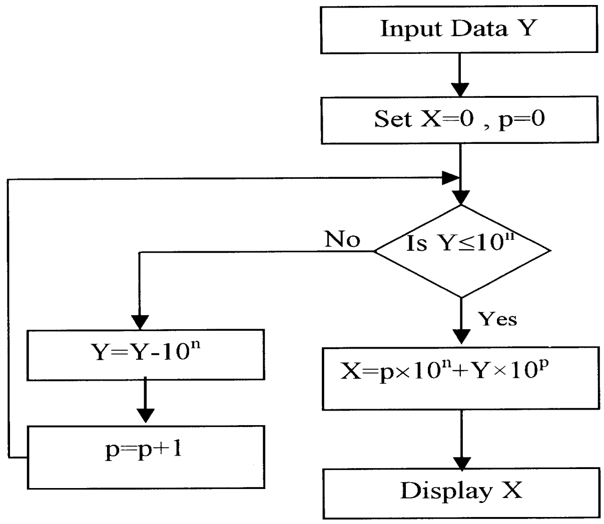


Figure 6. Proposed expansion algorithm.

$$X=a_{m}\cdot 10^{m}+a_{m-1}\cdot 10^{m-1}+\cdots+a_{m-n+2}\cdot 10^{m-n+2}$$
$$+a_{m-n+1}\cdot 10^{m-n+1} \qquad (9)$$

A graphical representation of this technique similar to Figure 4 is shown in Figure 7[5].

[5] Based on example shown in Figure.4

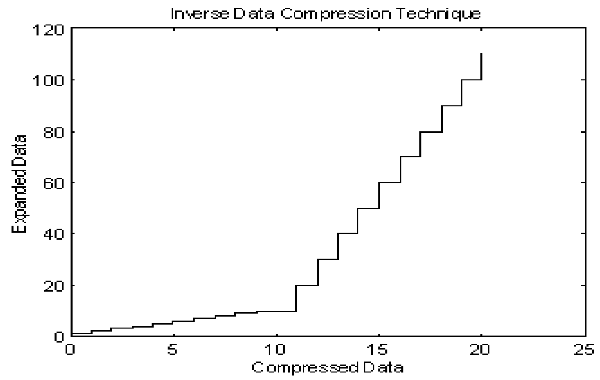


Figure 7. Graphical representation of data expansion technique.

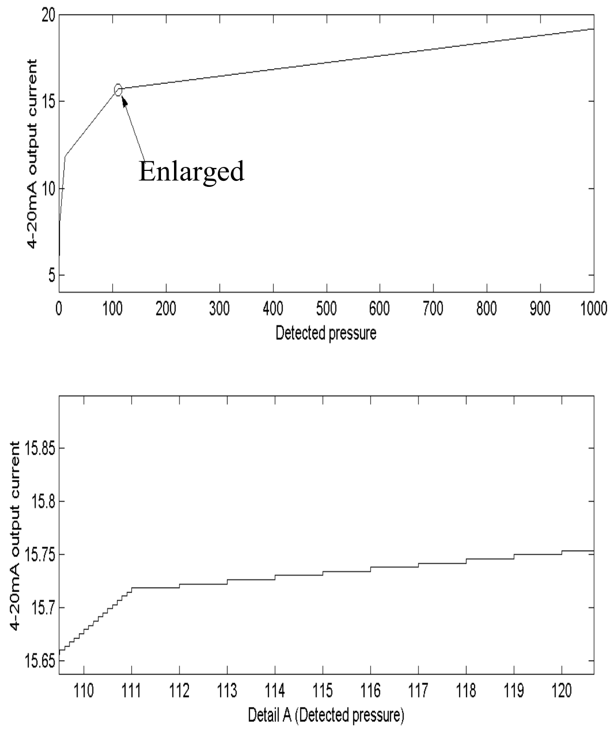


Figure 8. Data compression at transmitter side (Top) and enlarged section (Bottom).

Expanded Data

ELATIONSHIP BETWEEN ADCS, DACS AND THE COMPRESSED VARIABLE

Using a q-bit DAC to convert the compressed signal "Y" to an analog form will result in the followings:

$$(p+1)\cdot 10^{n} \le 2^{q} \quad (11)$$

$$p \le 2^{q}\cdot 10^{-n} - 1 \quad (12)$$

$$x \le 10^{p+n} \quad (13)$$

These expressions can be employed to determine the highest number (largest span) that can be achieved by an ADC or DAC. For example using a 12-bit DAC for a relative resolution of 0.001 will result in:

$$n = 3, q = 12$$

$$\Rightarrow p \le 2^{12}\times 10^{-3} - 1 = 3$$

$$\Rightarrow M < 10^{3+3} = 10^{6}$$

Where M denotes the largest compressible variable. This means that communication of variables with spans up to 6 decades and relative resolution of 0.1% is achievable just by a 12-bit converter.

At this point, it must be mentioned that the compression of data by this technique can be implemented using a divider at the transmitter and a multiplier at the destination.

The difficulty is lack of a communication line to synchronize the dividing & multiplying factors in both sides. Thus, the transmitting circuit requires an additional line, which complicates the system.

SIMULATIONS AND RESULTS

In this section the results from simulation of these algorithms for sending and receiving data for a pressure variable in a wide span 0-1000 bars with a relative resolution of 0.1% by a 4-20mA transmitter are shown.

In Figure 8, the simulation for data compression technique in an intelligent transmitter is presented. It can be observed that by changing the range, the gain of DAC changes automatically by software. On the other hand, Figure 9 shows the results of expanding the data. The input data is automatically scaled and there is no need to use switching circuits for automatic range selection. This technique is employed in the design of "an Intelligent Transmitter for CO gas

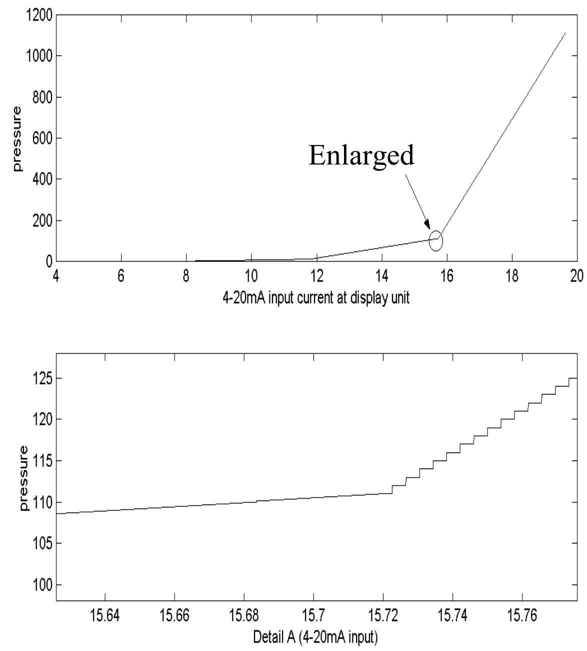


Figure 9. Data expansion at display unit (Top) and enlarged section (Bottom).

concentration detection" successfully [19].

CONCLUSION

For the first time a new technique for compression of data signals of 4-20mA transmitter is proposed, which compensates for the lack of small spans of high resolution processing variables. It is important to mention that a software algorithm performs this function automatically, during the procedure of data compression and expansion, instead of employing hardware techniques for range selection.

The simulation and practical results prove the efficiency of this technique.

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