APERTURE METHODS OF THE REDUNDANCY REDUCTION OF THE MEASURING INFORMATION IN TELEMETRY SYSTEMS

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Abstract

The classification of the methods of measuring information redundancy reduction in the telemetry systems and its comparative analysis are performed. The aperture methods are established to be the most suitable for the data redundancy compression techniques in the reduction of the measuring information in the telemetry systems. New aspects of the compression algorithm in the aperture method are developed on the basis of Taylor polynomials (extrapolation) and Lagrange polynomials (interpolation). The combined method — linear extrapolation on the transmitting side and the interpolation on the receiving side — is proposed to be used in the aperture approaches for data redundancy reduction. The combined approach is characterized by the absence of delay and a simpler algorithm realization on the transmitting side.

1. Introduction

At least three stimuli determine the necessity of the measuring data compression:

1) reduction of measuring data flow for the purpose of unloading, simplification, and rational use of communication channels, bandwidth reduction of communication lines frequencies, memory capacity reduction of measuring recorders and computers in the course of data processing;
2) operability increasing in compound object control due to fast data accessing from reduced data;
3) economy due to data compression regarding the simplification and reduction of the recording system volumes (the saving of magnetic carriers particularly, etc.).

Principal causes of measuring data redundancy initiation are the following [1]:

1) Unintentional overstatement of the measuring message component quantity, i.e., the prototype system examination in the state space of the overrated dimension.
2) Incomplete use of measuring message characteristics. It can be caused by physical failure of the optimum procedures that take account completely of a priori information, by realization complexity, etc. (the practical sampling rate is always more than the frequency defined by the Kotelnikov theorem for signals with finitary spectrum; it is difficult to apply approximation by means of the Karhunen-Loewe-Pugachev optimal basis in practice, etc.).
3) The impossibility in principle of full notion of realization behavior or examined characteristics of measuring messages (as the sense of measurements otherwise is lost), therefore, the telemetry gage system design is made on the basis of measuring message limit characteristics, as a rule. The question is the formation of the natural redundancy of the messages in this case.

Classification of the redundancy reduction methods.

The redundancy reduction methods during measurements can be classified as follows.

1) The compression techniques are divided in classes according to the type of the removable redundancy and taking into account the above for cause redundancy.

2) The compression techniques can be divided in analog messages, semidigital messages, and digital messages meant for processing according to the message type at the port.
3) There are methods of separate processing and multiple processing (coprocessing) according to the number of coordinates (elements) processed simultaneously by compression techniques.
4) It is possible to mark out the universal compression techniques and special compression techniques, i.e., using the measuring subject specific character according to the object domain of the compression techniques (i.e., according to the signal class). The special compression techniques of the voice signals, physical fields (images, etc.), text, etc. are known.
5) It is possible to distinguish reversible compression techniques (the restoration is possible) and irreversible compression techniques (the restoration of the reference message is impossible, for example, during the transition from the message to its autocorrelation function) according to the possibility to restore initial realization of the message with a controlled error.

Let us note some data redundancy compression techniques:

1) Aperture methods. Aperture methods are most effective with the use of the uniform precision factor (uniform metric). This precision factor is used often, especially during the design and new equipment tests;
2) Difference methods;
3) Group measuring representations;
4) Filtration as compression techniques;
5) Other techniques (including irreversible compression techniques).

2. Aperture methods

The aperture methods are the most developed methods of the measuring data redundancy reduction that are based on the input signal adaptive sampling at which the readout is considered insignificant and not subject to transfer if the approximation error does not exceed the maximum permissible value.

The functional ε(t) is calculated during the formation of the adaptive readout in one measuring channel on the sampling interval. This functional describes a divergence between the measured function x(t) and approximating function x*(t) on the interval (t_i, t)

$$\varepsilon(t) = \Phi[x(t^*)],$$

where t_i is the beginning of the sampling interval; t*E(t_i, t); t is the running time, belonging to the sampling interval.

The readout is considered significant in systems with preliminary uniform time discretization (UTD) under the conditions

$$\varepsilon(t_i + k\Delta T) \leq \varepsilon_{t,}$$
$$\varepsilon(t_i + (k+1)\Delta T) \leq \varepsilon_{t,}$$

where k = 0,1,...; ε_t is the threshold value of the precision factor (aperture); ΔT is the interval of the preliminary uniform sampling.

The Taylor polynomials (extrapolation) and Lagrange polynomials (interpolation) are used most often during the construction of data compression devices (DCDs) on the basis of aperture methods.

2.1. Extrapolation

The algorithm is based on use of Taylor series for construction of the signal estimation

$$x(t) = \sum_{i=0}^{n} \frac{x^{(i)}(t_0)}{i!}(t - t_0)^i. \qquad (1)$$

If the signal estimation on the basis of a polynomial of degree *n* is used, then signal selection and signal derivatives are subject of transferring (up to (*n* - 1)).
The discretization average interval of the stationary signal normally distributed at its polynomial approximation of degree *n*

$$\tau_n = \frac{(n+2)\sqrt{\pi}}{2(n+2)\Gamma[(3n+4)/(2n+2)]}\left[\frac{(n+1)i\varepsilon t}{\sigma_{n+1}\sqrt{2}}\right]^{\frac{1}{n+1}}, \qquad (2)$$

where σ_{n+1} is the mean-square value of the corresponding derivative.

The compression algorithm on the basis of the Taylor polynomial is one of the simplest. The algorithm consists in comparison of a difference of the signal next value $x(t_i+kT_0)$ and last transferred essential readout $x(t_i)$ with an admissible error (setting)

$$\left|x(t_i + k\Delta T) - x(t_i)\right| \le \varepsilon t .$$

The compression factor is approximately in a range from 2 to 4 depending on an approximation admissible error and distribution of a signal [2] for stationary signals and $n = 0$. The non-stationary signals algorithm provides the high compression factor defined by the non stationary mode.

If a small delay is possible during regeneration, it is admissible to use the interpolation regeneration [3] instead of the extrapolation regeneration. This reduces an error, on the other hand, and reduces interference effect on the compressor port, on the other hand.

The disadvantage of the extrapolation methods is the hypersensitivity of the input and channel errors.

2.2. Interpolation

The interpolation allows increasing the compression factor in comparison with the extrapolation. We note especially the linear interpolation as practically limiting on the realization complexity.

For $n = 1$ the average interval of the linear interpolation:

$$\tau_{1,i} = \frac{\sqrt{\pi}\sqrt[4]{2}}{\Gamma(3/4)}\sqrt{\frac{\varepsilon t}{\sigma_2}} \approx 2{,}3\sqrt{\frac{\varepsilon t}{\sigma_2}}, \qquad (3)$$

for linear interpolation:

$$\tau_{1,i} \approx 4{,}6\sqrt{\frac{\varepsilon_t}{\sigma_2}}, \qquad (4)$$

Having regard to correlation (2.2), we find the fractional increase of the average interval during transition from $n = 0$ to $n = 1$:

$$k_{10} = 3{,}7\frac{\sigma_1}{\sqrt{\sigma_2 \varepsilon t}}, \qquad (5)$$

The coefficients k_{10} make for signals with correlation functions $B_{x1}(\tau) = \sigma^2 R(\tau) = \sigma^2 \sin\alpha\tau/(\alpha\tau)$ (infinitely differentiable process) and $B_{x2}(\tau) = \sigma^2 R(\tau) = \sigma^2 \exp(-\alpha|\tau|)(1 + \alpha|\tau| + \alpha^2\tau^2/3)$ (double differentiable process), respectively,

$$k_{10} = 3{,}2\sqrt{\frac{\sigma}{\varepsilon_t}} \text{ and } k_{10} = 1{,}5\sqrt{\frac{\sigma}{\varepsilon_t}}.$$

The coefficient k_{10} is 13 for the first signal and 6 for second signal when $\varepsilon_t/\sigma = 0.06$, which corresponds approximately to the admissible error of 1%. The advantage during the transition from $n = 0$ to $n = 1$ is higher for a smoother signal and lesser admissible error. The higher noise immunity is another advantage of the linear interpolation.

The algorithm disadvantage is the more difficult algorithm realization and the delay during the data transmission equal to the approximation maximal interval. The maximal interval exceeds significantly the minimal interval for the non-stationary process that leads to the delay, on the one hand, and to the great volume of the RAM memory capacity needed, on the other hand. These disadvantages can be reduced considerably by entering the forcing sampling channel.

2.3. Combined methods

Linear extrapolation on two essential readouts. This algorithm is the linear extrapolation and linear interpolation updating: the derivative is defined on a difference of values of the successive essential readout of a signal and corresponding values of time. The algorithm is similar to the algorithm of linear interpolation in many respects, but the functioning is in real time without delay.

The noise immunity is slightly worse than during the linear interpolation, but is appreciably better than during the linear extrapolation. The average interval is less than during the linear interpolation by a factor of 2.4.

The linear extrapolation on the transmitting side and the interpolation on the receiving side. The algorithm functioning is clear from this title. Advantages: the absence of delay and a simpler algorithm realization on the transmitting side (though is higher than during the classical linear extrapolation) and necessity of the signal value transmission during the change of the sign of the second derivative in order to avoid the error doubling. The setting (aperture) is selected to be equal to the admissible approximation error in this case.

3. Conclusions

The classification of the methods measuring information redundancy reduction in telemetering systems is performed. It is established that the aperture methods are the most developed ones for measuring information redundancy reduction which are based on the adaptive digitization of input signals at which the readout is considered insignificant and not subject to transfer if the approximation error does not exceed the maximum permissible value.

The hypersensitivity to both input disturbances and channel disturbances is the disadvantage of the extrapolation methods of the measuring information redundancy reduction.

The interpolation allows increasing compression factor in comparison with the extrapolation. The linear interpolation is nearly limiting according to the realization complexity.

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