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Comparison of different types of multiplex systems from viewpoint of power consumption

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Abstract

The measurement signals average power both for adaptive and usual regular multiplex measurement systems are compared and the better effectiveness from viewpoint of power consumption is discussed in this paper.

Keywords: measurement system, power consumption, adaptation, compression.

Porównanie różnych typów systemów wielokanałowych z punktu widzenia poboru mocy sygnałów pomiarowych

Streszczenie

W artykule porównano klasyczne (regularne) i adaptacyjne wielokanałowe systemy przełączające z punktu widzenia poboru mocy sygnałów pomiarowych. Pierwsze z nich są projektowane według kryterium Nyquista, a drugie (przykładowo) - z wykorzystaniem predykcji zerowego rzędu oraz adaptacyjnego komutatora. Kompresja danych pozwala z jednej strony zmniejszyć wymagania, co do szybkości ich przetwarzania (związane jest to z pojemnością kanałów transmisyjnych), a z drugiej - wymaga wprowadzenia dodatkowej informacji (na przykład adresy aktywnego źródła, momentu jego aktywności itp.), co pogarsza efektywność kompresji. Określono warunki efektywności danego typu systemu z punktu widzenia przyjętego kryterium. Stwierdzono, że moc sygnałów pomiarowych w przypadku systemów adaptacyjnych może być znacznie mniejsza niż dla systemów klasycznych, gdy iloraz współczynników ks (liczba symboli binarnych na jedną próbkę) i kω (współczynnik określony, jako iloraz sumarycznych wartości średniokwadratowych częstotliwości sygnałów dla systemów klasycznych i adaptacyjnych) jest mniejszy od 2.5.

Słowa kluczowe: systemy pomiarowe, zapotrzebowanie mocy, adaptacja, kompresja.

1. Introduction

Analogue source sampling digital multiplex systems are well known nowadays [1-4]. Thanks to compression techniques [2-4], the adaptive multiplex time-division systems make it possible to decrease the requirements to the channel capacity unlike the regular multiplex time-division systems based on the Nyquist sampling theorem. However, the data stream becomes stochastic, and some part of the channel capacity is wasted on the additional services such as addresses. Thus, on the one hand, the adaptive system eliminates the redundant samples and, on the other hand, the number of binary symbols per sample increases.

The presence of service words and the link noise make the compression effects worse. Parity check coding was used for the purpose of erasing the wrong code words. It was noticed that for a certain frequency of totality of sources, the adaptive system can perform even worse than the regular time division system [7]. Having the same totality of sources and other similar conditions, these systems were compared according to their channel capacity requirements. Estimations for the proper (in the sense of an optimal use of channel capability) choice of the system type (regular or adaptive) had already been found earlier [5, 6]. However, it is desirable to minimize both system operational time and requirements for the power consumption [4]. These criteria are in correspondence with the energy expenditures on the data transmission. However, in the first case the probability of one bit distortion is considered to be fixed and in the second case it is the interior parameter of the multichannel system. Energy approaches obtain the integrity of measurement transformations estimations. As an example, let us take into consideration the same probability of single bit distortion both for regular and adaptive switching types systems. Assuming the pulse code modulation with the subsequent frequency manipulation via the channel with white Gaussian noise presence, this probability is calculated as follows [4, 8]

$$p = \frac{1}{2} e^{-\frac{P_c}{2N_0 R}}, \qquad (1)$$

here P_c is the measurement signal mean power; N_0 is spectral density of the white noise power; R is the rate of the measurement signal processing (top index A corresponds with adaptive system and U corresponds with regular non-adaptive one). Thus, we obtain

$$\frac{P^A}{N_o R^A} = \frac{P^U}{N_o R^U} \text{ or } \frac{P^A}{P^U} = \frac{R^A}{R^U} \qquad (2)$$

and therefore consider the ratio of rates R^A / R^U as the next.

2. Rate demands requirements and comparison

Regular type system analysis

The regular system total error consists of the sampling, quantization and channel effect components. So, the relative mean-square sampling error estimation at the r-th quasi-stationary time interval of the i-th analogue signal [9] is

$$\delta_d^2 = \frac{1}{3}(\omega_{1i} T_i)^2 , \tag{3}$$

here T_i and ω_{1i} are the i-th source sampling period and mean-square frequency, respectively.

The relative mean-square quantization error estimation expression is as follows

$$\delta_q^2 = \varepsilon^2 / 12 , \tag{4}$$

here $\varepsilon = \Delta/\sigma$ and Δ is relative and absolute quantization steps, respectively; σ is the i-th signal mean-square deviation.

At the same time, let us assume that synchronization is reliable and correct. The link noise effect error can also be considered as some accumulated sampling errors random number k with geometric distribution [4] and thus, the loss probability is equal to $P_l = p(m_i + 1)$ and the relative mean-square loss error estimation is given by

$$\delta_l^2 = \delta_d^2 p(m_i + 1) , \tag{5}$$

here P_l is the sample loss probability.

The total mean-square error estimation, according to (3) - (5) and, additionally, including the instrumentation error δ_i, is as follows

$$\delta^2 = \frac{1}{3}(\omega_{1i} T_i)^2 [1 + p(m_i + 1)] + \delta_q^2 + \delta_i^2 \tag{6}$$

and its corresponding i-th sampling period

$$T_i = \sqrt{3} \frac{1}{\omega_{1i}} \sqrt{\frac{\delta^2 - \delta_i^2 - \delta_q^2}{1 + p(m_i + 1)}} . \tag{7}$$

The *i*-th source intensity $\lambda_i = 1/T_i$, hence the time division multiplex system commutator switching time is following

$$T = 1/\lambda = 1 \Big/ \sum_{i=1}^{n} \lambda_i = \left[\sum_{i=1}^{n} 1/T_i \right]^{-1} . \tag{8}$$

Taking into consideration the same quantization error for all system sources and expression $T = (m_i + 1)T_o$, the rate requirements estimation may be expressed as follows

$$R^U = \frac{1}{T_o} = \frac{\sqrt{1 + p(m_c + 1)}}{\sqrt{3(\delta^2 - \delta_i^2 - \delta_q^2)}} (m_i + 1) \sum_{i=1}^{n} \omega_{1i} , \tag{9}$$

here $\omega_c^u = \sum_{i=1}^{n} \omega_{1i}$ is the total sources mean-square frequency of a regular type time division multiplex system.

The adaptive sampling system analysis

The regular time-division system procedure is based on the Nyquist theorem [8, 9]. It is based on the highest source frequency, which causes the information redundancy of the totality of sources. That is why the measurement systems adaptive to the data stream appeared. Such compression techniques are used to decrease the requirements for the communication channel capacity or to the data processing rate.

The most widespread data compression systems are based on the prediction or the adaptive switch principle [4]. As an example, the adaptive sampling system based on the adaptive switching operational principle was taken into consideration (Fig. 1).

This type of an adaptive sampling system looks through all analog sources with a constant rate in time interval *T* (Fig. 2). Here, all analogue sources are sampled at a constant rate with the period *T*. In each sampling point, the adaptive switch chooses the most active source from the totality of sources, i.e., the chosen source has the largest absolute value of the difference of its two serial samples, normalized with respect to the mean-square deviation of this source analogue measurement signal. The samples of the other sources are supposed to be redundant. The i-th most active source sampling value occurs in the i-th memory cell for the next sample time comparison.

Practically the i-th source difference is estimated by subtracting the current sampling moment value from the previous activity manifestation value, which is picked up from its memory cell. Then, the unit operates with the difference modulus.

The total error of such a type of an adaptive sampling system includes sampling, quantification, instrumentation and link noise effect components [4 - 6].

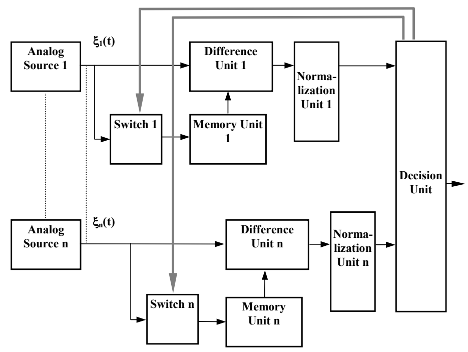

Fig. 1. Activity analyzing unit based on the adaptive switch
Rys. 1. Moduł analizy aktywności wykorzystujący przełącznik adaptacyjny

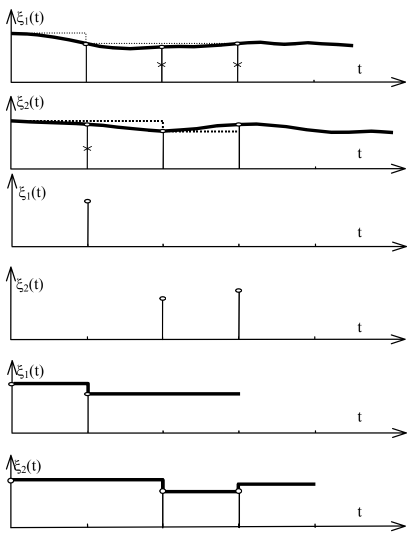

Fig. 2. Adaptive switching sampling time diagram
Rys. 2. Diagram czasu próbkowania przełącznikiem adaptacyjnym

The mean-square sampling error estimation [4] is as follows:

$$\delta_d^2 = \frac{2}{3 \cdot \pi} (\omega_\Sigma^A \cdot T)^2 \tag{10}$$

here ω_Σ^A is the sources totality mean square frequency calculated for the adaptive type system.

Fluctuation noise in the link can lead to mutilation of both data and address parts of the message [4,10]. Let us consider the digital link that can be represented by a binary symmetric channel, where in the symbol transformation probability *p* of a zero to a one or opposite is the same, the probability of correct transmission is therefore (1-p), and then separately-check the information data and address parts using [4, 10]. So, this mean-square error component is

$$\delta_{ch}^2 = \varepsilon^2 p m_c^A , \quad (11)$$

here $m_c^A = m_a + m_i + 2$, m_i and m_a are measurement and address symbols number, respectively.

The quantization error is the same as for a regular type digital system.

The total relative mean-square error estimation, according to expressions (4), (10), (11) and including the instrumentation error δ_i, is equal to

$$\delta^2 = \delta_i^2 + \frac{\varepsilon^2}{12}\left(1 + 12 p m_c^A\right) + \frac{2}{3\pi}\left(\omega_\Sigma^A T\right)^2 , \quad (12)$$

here δ is the relative mean-square admissible restoring error value for the i-th source (assuming that this value is equal for the totality of all sources).

Let us note that the total error value is the same both for regular and adaptive types of systems.

The expression for the data rate R estimation, being inversely proportional value to the symbol time duration T_0, was found using the sampling component (10) of the full mean-square error estimation (12), and is as follows:

$$R^A = \sqrt{\frac{2}{3\cdot\pi}} \cdot \frac{m_c^A}{\sqrt{\left(\delta^2 - \delta_i^2 - \delta_q^2\right) - \varepsilon^2 p m_c^A}} \omega_\Sigma^A . \quad (13)$$

Taking into consideration the ratio of expression (13) to expression (9), we have

$$\frac{R^A}{R^U} = \sqrt{\frac{\delta^2 - \delta_q^2 - \delta_i^2}{\left[\left(\delta^2 - \delta_q^2 - \delta_i^2\right) - \varepsilon^2 p m_c^A\right]\left[1 + p m_c^U\right]}} \times \sqrt{\frac{2}{\pi}} \left(\frac{m_c^A}{m_c^U}\right)\left(\frac{\omega_\Sigma^A}{\omega_\Sigma^U}\right) . \quad (14)$$

Analyzing expression (14) we obtain

$$\frac{R^A}{R^U} = \left(\frac{k_s}{k_\omega}\right)\frac{1}{\sqrt{2\pi}}\left(1 - p m_c^U + \frac{12\delta_q^2 p m_c^A}{\delta^2 - \delta_q^2 - \delta_i^2}\right) . \quad (15)$$

Hence, two last components are essentially less than one, therefore

$$R^A / R^U \approx \left(k_s / k_\omega\right) 1 / \sqrt{2\pi} , \quad (16)$$

here $k_s = m_c^A / m_c^U = \left(m_a + m_i + 2\right) / \left(m_i + 1\right)$, $k_\omega >$ 1 and $k_\omega = \omega_\Sigma^U / \omega_\Sigma^A$; ω_Σ^U and ω_Σ^A are the sources totality mean square frequency calculated for the system of regular and adaptive type, respectively.

So, we obtain the following conclusion

$$\frac{R^A}{R^U} < 1 \text{, if } \left[k_s / \left(k_\omega \sqrt{2\pi}\right)\right] < 1 \text{ ; } \left(k_s / k_\omega\right) < \sqrt{2\pi} \approx 2.5 . \quad (17)$$

Note that the mean-square frequency is determined at a certain quasi-stationary time interval, but random from one interval to another. If the i-th mean-square frequency probability distribution is known, it is possible to find its guaranteed value with a certain given probability $\omega_{1\max i} = M\omega_{1i} + a\sigma_{\omega 1i}$, here $M\omega_{1i}$ and $\sigma_{\omega 1i}$ are the mean and mean-square deviation, respectively, the i-th source mean square frequency, a is guaranteed probability coefficient.

Due to the regular system methodology designing

$$\omega_\Sigma^U = \sum_i \omega_{1\max i} = \sum_i M\omega_{1i} + a\sum_i \sigma_{\omega 1i} , \quad (18)$$

moreover, regarding the adaptive one, the total mean-square frequency probability distribution approximation considers the Gaussian with the mean value $\sum_i M\omega_{1i}$ and the mean-square deviation $\sqrt{\sum_i \sigma_{\omega_{1i}}}$. Hence, the guaranteed total system mean-square frequency estimation is as follow

$$\omega_\Sigma^A = \sum_i M\omega_{1i} + a\sqrt{\sum_i \sigma_{\omega 1i}^2} . \quad (19)$$

Hence, returning to the expressions (2) and (17) we obtain the condition of the adaptive system effectiveness in power consumption point of view as follows:

$$P^A / P^U < 1 \text{, if } k_s / k_\omega < 2.5 . \quad (20)$$

3. Conclusions

The measurement signal power of the adaptive system can be much less than for the regular system, when the fraction of the ratio between the numbers of binary symbols per one sample k_S and of the ratio of the sources totality mean square frequencies k_W for these systems (at the same precision and the same probability of one binary symbol distortion) is less than 2.5. The requirements for the signal power and channel capacity are agreed at the same allowed error of measurement signal renovation.

4. References

[1] Cover T., Thomas J.: Elements of Information Theory. John Wiley & Sons, Inc., New York, /Chichester / Brisbane / Toronto / Singapore, 1991, 542 p.

[2] Turner L.F.: Data compression techniques as a means of reducing the storage requirements for satellite data: a quantitative comparison, The Radio and Electronic Engineer no. 43 (10) (1973) 599-608.

[3] Stranneby D.: Digital signal processing: DSP and Applications., Elsevier Inc., 2001.

[4] Kalashnikov I.D., Stepanov V.S. and Churkin A.V.: Adaptive Data Gathering and Transmission Systems (in Russian). Energiya Press, Moscow, 1975, 240 p.

[5] Ivakhiv O., Velgan R.: Digital Measurement Systems Comparison, Proc. of 10th International Symphosium on Development in Digital Measurement Instrumentation, Naples, Italy, September 17-18, 1998, vol. 1, pp 40-44.

[6] Fedorchuk A., Ivakhiv O., Velgan R.: Comparative Time-Division Digital Multiplex Systems Analysis, Proc. of the 6-th International Methrologyst Seminar Methods and Technics of Signal Processing in Physical Measurements Lviv-Slavsko, Ukraine, June 17-19, Rzeszow, Poland, Oktovber 26-28, 1998, pp 78-81.

[7] Vasylyk Yu., Ivakhiv O.: The measurement-computer network terminal organizing manner comparison, Herald of Lviv Polytechnic State University (in Ukrainian) #283, 1994, pp 66-74.

[8] Wozenkraft J.M., Jacobs I.M.: Principles of Communication Engineering. John Wiley&Sons Inc. – New York-London-Sydney, 1965

[9] Teplyakov I.M., Kalashnikov I.D., Roshchin B.V.: Sattelite Data Transmission Radio Links (in Russian). Sovetskoe Radio Press, Moskow, 1975, 400 p.

[10] Ivakhiv O., Karlov A., Cherkasov V.: Influence of the channel on continuous message transmission quality in adaptive data transmission systems. Radioelectronics and Communications Systems, vol.20, No.3, 1997, Allerton Press Inc., pp. 8-15.

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