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Temperature Distribution Measuring System

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Abstract

The pyrometer moving along the stove axis can be used for the surface temperature measurement of the circulating cement stove. By the temperature distribution along the rotor stove measuring, all possible temperature values in space and time can be described using a simple two-dimensional random temperature field model. Thus, the measuring signal is redundant, and it is possible to use the known compression techniques in order to reduce the requirements to the measuring information processing rate. The paper presents expressions estimating the parameters of this kind of adaptive system.

Keywords: adaptive, measurement system, temperature.

System pomiarowy do wyznaczania rozkładu temperatury

Streszczenie

Pomiar rozkładu temperatury powierzchni pieca do wypalania cementu zrealizowano za pomocą pirometru poruszającego się wzdłóż osi pieca. Jako dane pomiarowe do modelu matematychnego rozkładu temperatury w czasie i przestrzeni wykorzystano dwuwymiarowe pole losowe temperatury zarejestrowane pirometrem. W związku z faktem, że sygnał pomiarowy zawiera więcej niż potrzeba informacji, należy wykorzystać znane metody kompresji danych, umożliwiające spełnienie wymagań dotyczących szybkości przetwarzania danych pomiarowych. W pracy podano odnośne wzory służące do obliczeń w takim adaptacyjnym systemie pomiarowym.

Słowa kluczowe: system pomiarowy, temperatura, adaptacja.

1. Introduction

Numerous technological processes deal with the temperature distribution measurements, carried out in space, on a plane or along some line [1-2]. Thus, at some point in space the temperature value appears to be random in time and in space. It can be interpreted as a random vector, where constituents are time and geometrical coordinates [3]. In particular, each value of temperature field set of the circulating stove turns out to be a casual function of at least two arguments such as geometrical coordinate (i.e., position on the axis of stove) and time. Therefore, by using the temperature distribution along a rotor stove measurement we can take advantage of the two-dimensional random temperature field model as in aggregate of all possible temperature values in space and time. Changeability of temperature in time depends on the frequency properties of the field, and the amount of crossings of a certain possible temperature level depends not only on the set value of the tolerance area but also on the behavior of the temperature along the axis of the stove. In each point of geometrical coordinate as a result of the temperature field intersection with the plane perpendicular to the geometrical coordinate the dependence of temperature on time is a random process, and the change of temperature along a circulating stove axis at a certain moment (the section of the temperature field by a plane perpendicular to the time co-ordinate) can also be interpreted as the random function. Thus, this is a locus of the random vector projections in the proper plane. It is possible to use a scan pyrometer as an instrument for the measurement of the circulating cement stove surface temperature by moving it along the stove axis [4]. At first this instrument transforms the temperature values to electrical ones and then performs an analog-to-digital conversion with subsequent digital processing of the measuring signal. Since the requirements to digital processing turn out to be limited due to the precision of the processing, it is possible to take advantage of the known methods of the measuring information compression [5, 6]. It diminishes the requirements laid to the data transmission rate.

2. Basic Research for System Design

In case of temperature value measurement at a certain point, it is possible to set the defined tolerance value upwards and downwards in relation to the measured value in order to let the two planes pass through these points, parallel to the co-ordinate plane of *xOt*. Its reaching the mentioned temperature value will testify to the availability of temperature changes equal to the predetermined permissible tolerance value. This exactly coincides with the permissible value equal to the absolute error of temperature quantum of the digital instrumentation. It describes the so-called zero-order prediction principle, which makes it possible to decrease the sample stream intensity of the temperature process with the required accuracy of the temperature field renovation. The number of non-redundant samples per time unit (intensity) is determined [6] using the expression:

$$\lambda_t = \frac{\sigma_i}{\Delta U}\sqrt{\frac{2\left[-R_t''(0)\right]}{\pi}} = \sqrt{\frac{2}{\pi}}\cdot\frac{\omega_{1i}\sigma_i}{\Delta U} = \sqrt{\frac{2}{\pi}}\cdot\frac{\omega_{1i}}{\varepsilon_i}, \quad (1)$$

where ω_{1i} and σ_i is the mean-square frequency and the mean-square deviation of the stationary random temperature field; ΔU and ε_i are the quantum error value being absolute and normalized in respect to the mean-square deviation of the measuring signal, accordingly; $R_t''(0)$ is the second derivative of the coefficient of correlation in time co-ordinate at zero point.

The value of temperature along the axis of stove is also random. Therefore, the mean value of the plane intersections per one unit of the length axis will be determined as follows:

$$\lambda_l = \sqrt{\frac{2}{\pi}}\cdot\frac{\sqrt{\left[-R_l''(0)\right]}}{\Delta U}\cdot\sigma_i = \sqrt{\frac{2}{\pi}}\cdot\frac{\sqrt{\left[-R_l''(0)\right]}}{\varepsilon_i}, \quad (2)$$

where $R_l''(0)$ is the second derivative of the coefficient of correlation in a geometrical co-ordinate (length) at zero point.

It is possible to find the mean time interval $\overline{T}$ between two neighboring non-redundant samples as a reverse to intensity λ_t and the mean distance $\overline{L}$ reverse to the value λ_l between these samples along a stove [2]. So, using the expression (1) and (2) it is possible to estimate the requirements laid to the mean speed of the pyrometer motion as follows:

$$V_m = \frac{\lambda_t}{\lambda_l} = \frac{\overline{L}}{\overline{T}} = \frac{\omega_{1i}}{\left[-R_l''(0)\right]}. \quad (3)$$

Since substantial samples at the output of the compressor appear at the random moments, in order to work with a synchronous communication channel it is necessary to align such a sample stream, for example, by buffer data storage. The intensity of the buffer input stream depends both on the intrinsic frequency characteristics of the temperature field and on the pyrometer motion speed along a stove. The geometrical intensity (2) i.e., the sample intensity on the axis length unit, transforms into the corresponding intensity in time, namely:

$$\lambda_{lt} = \lambda_l V. \quad (4)$$

Suppose we take the speed of pyrometer motion equal to the mean speed (i.e., $V = V_m$), then according to expressions (3) and (4) we get the following:

$$\lambda_{lt} = \lambda_l V_m = \lambda_t.$$

From an immobile pyrometer, which is positioned at a certain point along the axis of stove, on the average there will enter λ_t non-redundant samples at the buffer store input during a time unit. The combined stream formed both by the random changes along a geometrical axis and by the changes in time of the two-dimensional field, will be brought from the mobile pyrometer. Thus, the general sample intensity λ at the buffer store input will be determined by the sum of the sample intensity in two co-ordinates: in time co-ordinate (1) and the geometrical co-ordinate (2) transformed in time:

$$\lambda = \lambda_t + \lambda_{lt}. \quad (5)$$

In particular, according to expressions (3) - (5) in case of pyrometer moving with average speed we get

$$\lambda = 2\lambda_t. \quad (6)$$

The selective non-redundant samples are loaded into the buffer store until they turn into a synchronous channel. The duration of such expectation is random. Thus, as the appearance of the original value of the selective sample at the compressor output and its appearance in a communication channel differ, it is necessary to carry out the additional additional time mark attachment. This can be done using the time mark generator [6], namely by involving some time marks in the non-redundant sample stream, i.e., codes with special correlation properties which makes their effective recognition possible. Time marks are produced with the permanent period T_M.

3. System Error and Processing Rate Estimation

The digital system processing rate is similar to the regular adaptive system formed in accordance having a structure of the zero-order predictor with the buffer data storage and a time mark generator [6]. The main units of the measurement system structure (fig. 1) are as follows: a moving pyrometer, zero-order predictor, buffer storage memory, time mark generator, coder, decoder, communication link, zero order interpolator and display. There are typical sources of errors such as the error due to the prediction procedure, due to the possible losses in buffer data storage, due to the sample displacement from the real time position at their even exposure at the time mark period as the analog signal renovation takes place, as well as due to the channel noise effect in a communication link [6].

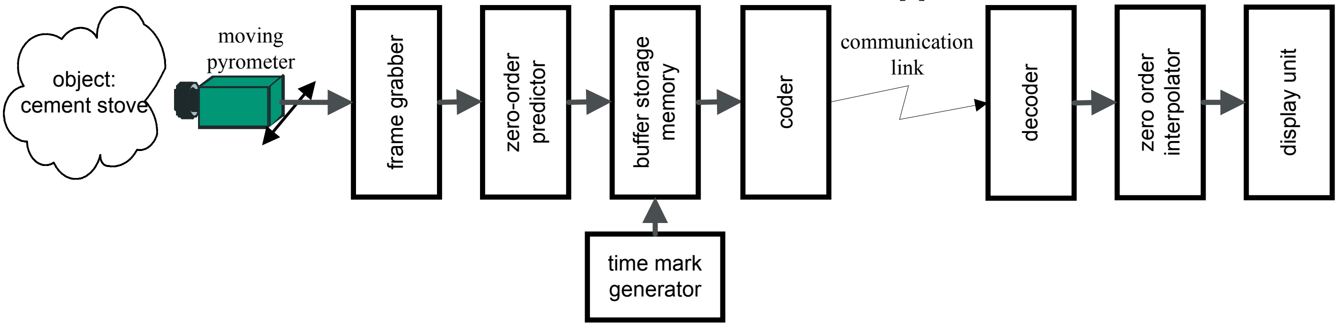

Fig. 1. Measuring system block diagram
Rys. 1. Schemat blokowy systemu pomiarowego

The mean-square prediction error value normalized in respect to the variance of the measuring signal is determined as

$$\delta_{pr}^2 = \varepsilon^2 / 12 , \tag{7}$$

where $\varepsilon=(\Delta U)/\sigma$ is the absolute prediction error ΔU normalized in respect to the mean-square deviation σ of the measuring signal.

The mean-square error due to the possible sample losses caused by the buffer storage overloading, normalized in respect to the measuring signal variance, is determined using the expression

$$\delta_{los}^2 = \varepsilon^2 \frac{P_{los} \cdot (1+P_{los})}{(1-P_{los})^2}, \tag{8}$$

where P_{los} is the probability of the sample losses.

The mean-square signal renovation error due to a possible time displacement of the measuring signal sample on the system receiving side, normalized in respect to the measuring signal variance, is estimated as follows:

$$\delta_{dis}^2 = \frac{\varepsilon^2}{6} \rho k_M , \tag{9}$$

where ρ is the coefficient of the buffer storage overloading; $k_M=T_M/T$ is the time mark period T_M normalized in respect to the synchronous channel time step T.

The mean-square error due to the possible sample distortion by the channel noise effect in the communication link, normalized in respect to the measuring signal variance, is determined applying the parity characters in a code word checking with the disfigured words elimination, namely:

$$\delta_{ch}^2 = \varepsilon^2 p (m_i + 1), \tag{10}$$

where p is the probability of single binary character distortion.

The system total mean-square error, normalized to the measuring signal variance, can be found using the expressions (7) - (10) taking into account the instrumental constituent δ_t, as well:

$$\delta^2 = \delta_{pr}^2 \left(1 + \frac{12 P_{los} (1+P_{los})}{(1-P_{los})^2} + 2\rho k_M + 12 p (m_i + 1) \right) + \delta_i^2 . \tag{11}$$

Jointly solving equations (1) and (11), we find the expression for the digital processing rate estimation requirement normalized according to the measuring signal mean-square frequency of the temperature field distribution. Let us note that the average speed estimation (3) of the pyrometer moving along circulating stove was taken into consideration. In the expression (11) we can separate the mean-square prediction error δ_{pr}^2 and after jointly solving equations (1), (6) and (7) we are able to find the relation between total intensity λ and mean-square frequency ω_{1i}, i.e.,

$$\lambda = \sqrt{\frac{2}{3\pi}} \cdot \frac{\omega_{1i} s}{\sqrt{(\delta^2 - \delta_i^2)}} , \tag{12}$$

where $s = \sqrt{1 + 12 \frac{P_{los}(1+P_{los})}{(1-P_{los})^2} + 2\rho k_M + 12pm}$, $m = m_i + 1$.

Non-redundant samples enter the buffer storage memory with the intensity λ and go out to the synchronous communication link with time interval T , so the buffer storage coefficient is as follows:

$$\rho = \lambda \cdot T \tag{13}$$

During this interval it is necessary to send m binary symbols, i.e., m_i symbols for the digital estimation of temperature value and one binary symbol for the parity checking as follows:

$$T = (m_i + 1)\tau = m \cdot \tau , \tag{14}$$

where τ is single binary symbol duration.

The digital processing rate R normalized in respect to the measuring signal mean-square frequency for the temperature field distribution estimation along the stove axis is inverse to the duration τ. Using the equations (12)-(14) we get

$$\frac{R}{\omega_{1i}} = \sqrt{\frac{2}{3\pi}} \cdot \frac{m}{\rho \sqrt{(\delta^2 - \delta_i^2)}} \cdot s . \tag{15}$$

In case the system serves several stoves, it is necessary to indicate each of them with an individual number ($m_a = \log_2 n$ is the number of the stove address symbols, where n is the number of stoves). The total binary symbols $m = m_i + m_a + 2$ and the rate R are here normalized in respect to the totality sources mean-square frequency $\omega_{1\Sigma} = \sum_i \omega_{1i}$.

For the pyrometer moving along the circulating stove, the mean linear speed is calculated according to expression (3). The above expressions for basic characteristics of the scanning system for the temperature distribution circulating stove make it possible to increase the effectiveness of the measurement procedure.

4. Conclusion

The adaptive principles used in the scanning measurement system of the temperature distribution field while designing the cement burning out enable us to decrease the requirements both to the measurement information processing rate and to the instrumentation power consumption as well as more effectively communication channel capacity using. Time and geometric axes being temperature value identifying components depend on their correlation properties. They effect the mean-linear speed value. Let us note that the motion with mentioned speed provides transformation of the geometric intensity component into the time axis equal to the time intensity component.

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Artykuł recenzowany