described in article, can be used to project automated systems with dynamic structures, which will be built on the basis of the proposed approach; for calculating complex indicators when processing statistical information.

The development of the approach is planned in the following ways:

– the revealing of the structure representing the indicator graph, features of its construction and the traversal algorithms;

– researching invariable database control system storage methods for graph indicator, qualifiers, and factual data; working out techniques to work with account elements in these systems;

– researching possible automatic processing ways for factual data: in order to reveal doubtful data, new complex indicators, and new data classes for further analysis.

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THE APPLIED METHOD FOR CARRIER FREQUENCY RESTORATION OF THE TELEMETRY SYSTEMS SIGNAL BY DIGITAL PROCESSING

The paper considers the issue of restoring the level of the telemetry signal carrier frequency at digital processing in the automatic carrier control tract and the calculation of the threshold for taking the decision about the validity of received information symbol from the spacecraft and carrier rocket. We have described the applied method and algorithm for calculating the level of the carrier frequency and the level of threshold for making a solution based on histogram processing of the signal from the output of the frequency detector.

Keywords: control system, signal processing, telemetry.

The control of flight task execution by class SC/CR onboard systems is performed based on the processing of telemetric data (TMD) on the status of most units and devices of the object [1]. For a satisfactory receipt and processing of TMD achieving proper ground means that the following parameters are required for positive detection of received char (“0” or “1”): the restoration of radio signal carrier frequency and the calculation of decisions making the threshold.

Currently, the fast Fourier transformation (FFT) or data parameter linear filtering procedures are usually applied to repair carrier frequency of carrier-shift radio signal [2]. The use of FFT requires a large number of processing operations to get a necessary result, and consequently, a significant time to analyze the signal. The linear filtering (LF) usage leads to complicity for unbiased signal estimate under processing. Besides, the usage of conventional approaches (FFT and LF) for signal processing on a significant noise background does not allow positive detecting of carrier frequency radio-signals [3]; this considerably decreases the sensitivity of radio receiver digital channels.

Alternatives to FFT and LF correction carrier frequency procedures and algorithms are still insufficiently presented in Russian and foreign studies [4–6]. Therefore a development of procedures and algorithms (P&A) for carrier frequency correction (CFR) based on the histogram procedure is considered to be rather urgent, since this method would require considerably less computing sources than FFT.

The CFR procedure presented in this paper is developed based of the histogram procedure. The point of the procedure is the following: the range of possible signal levels at the detector’s output frequency is divided into an optimal number of control levels or intervals. The signal beyond the frequency detector output is transferred to histogram level construction units (HLCU). The amplitude of the signal is compared to the value of the control levels in HLCU; the number of values for the signal amplitude within the interval $\Delta_k = \frac{A_k - A_{k-1}}{2}$ is registered. A_k and A_{k-1} – values of neighbor control levels. A one-dimensional vector (vector of the amount values within interval $\Delta(k)$ is generated –

histogram $H(k)$. The storage vector $S(k)$ or sum vector of the signal levels within the interval $\Delta(k)$ is generated at the same time. Signal max and min levels are detected by the histogram values. The average value of the upper (or lower) signal level is calculated by the next step, based on $H(k)$ the upper limits' value and stored (accumulated) signal max value $S(k)$ (sce figure).

Figure presents an output signal of the frequency detector $A(t)$ for a typical binary receiver and the histogram corresponding to the signal. Two upper limits of the histogram $H(k)$ correspond to upper level A_1 and lower level A_0 signals. The values of the upper limits are identified by quantity of "0" and "1" chars in estimated interval of data message; if the number of chars "0" is equal to the number of chars "1" then the amplitude of the upper limits is also equal to each other. When noise level increase, the upper limits come into a single upper limit which corresponds to the rationing of average signal and noises levels. The interval between the upper limits is determined by a signal swing. The center $(A_1 + A_0)/2$ of the interval is a level of the carrier and depends on frequency mismatch only. Also the center of the interval is an optimal threshold for decision devices which quantizes analog signal from the frequency detector into binary levels "1" and "0". Signal $D(t)$ at output of decision, taking circuit, is a binary image of signal $A(t)$ (sce figure).

The amount of "0" and "1" in data message can be very different for each separate time period. Maximum number of "0" or "1" (as shown at the histogram $H(k)$ in figure) defines the average current value of "0" ("1"). The interval between the histogram's upper limit levels is divided into half; so, the value is considered as an average level of repaired carrier frequency [6; 7].

Thus, the CFR method, applying the histogram procedure includes the following stages:

1. The identification of the interval where "1" and "0" signal levels are estimated. It's defined that the best results occur if the estimated interval is equal to the interval of signal accumulation levels for an automatic frequency control circuit. This is related to the fact that signal level has minimum changing during this interval.

2. The calculation of a number of signal levels within control intervals and the accumulation (storage) of signal current levels for each row of the histogram at the interval under processing.

3. The determination of the histogram's upper limits and the computing of average current level of the carrier frequency.

4. Correction of the input signal.

The general features of the procedure are:

– provision of the carrier level linear dependence estimation from frequency mismatch;

– provision of the carrier average level unbiased estimate (its level does not depend on the amount of "1" and "0" in data message);

– high resistivity of the carrier level repair algorithm (at high noise levels) which is developed on the basis of the procedure suggested in this study.

The following algorithm is developed on the basis of the suggested procedure**.** The frequency detector output histogram $H(k)$ is plotted on a time interval equal to $\tau_{\text{АПЧ}}$. The number (k) of ranges or rows in the histogram is determined by required accuracy calculation and by the certainty of upper limits detection corresponded to char signal levels.

The sums $S(k)$ are calculated in parallel for the histogram's k ranges.

Then the following operations are performed:

1. Determination of $\max_0 = H_{(k=mx0)}$ and $\max_1 = H_{(k=mx1)}$ values which correspond to levels of "0" and "1" signals.

2. Estimation of average level: $\hat{A}_0 = S_{(mx0)} / n_{(mx0)}$ and $\hat{A}_1 = S_{(mx1)} / n_{(mx1)}$, where $n_{(mx0)}$ and $n_{(mx1)}$ is the number of accounts for the appropriate levels, $\hat{A}_H = (\hat{A}_0 + \hat{A}_1)/2$ – the estimation of the average carrier frequency level (CF) coming to a predictor.

Let's introduce the following signs:

$\hat{A}_H = Y(k)$ – the estimation of CF level for k moment of time;

$\tilde{A}_H = Y(k+1 \mid k)$ – the output value of the extrapolator, which is the optimal threshold for the taking decision circuit (the circuit quantizes frequency detector counts to chars "0" and "1").

In general case, the extrapolator is defined by an equation of the following class:

$$Y(k+1 \mid k) = F\left[Y(k), Y(k-1), ..., Y(k-(r-1))\right],$$

where F – a certain function of r indeterminate values; r – extrapolator's memory depth.

Tracker unit uses 2 predictors: linear extrapolator – for two points ($r = 2$) and quadric extrapolator – for 6 points ($r = 5$):

$$Y_1(k+1 \mid k) = 2 \cdot Y(k) - Y(k-1),$$

$$Y_2(k+1 \mid k) = \big(9 \cdot Y(k) - 4 \cdot Y(k-2) - \\ - 3 \cdot Y(k-4) + 3 \cdot Y(k-5)\big)/5.$$

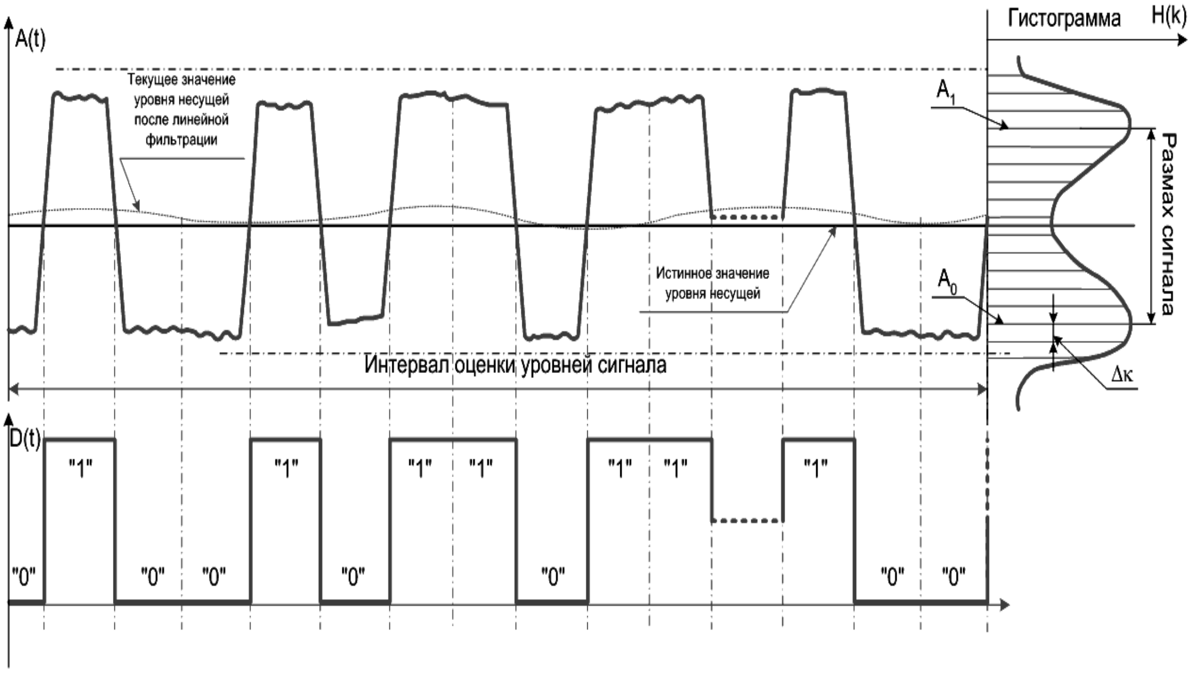
The results of the predictors computing are joined for collateral extrapolation of linear, quadric etc. dependence of parameter $Y(k)$:

$$Y_\Sigma(k+1 \mid k) = \sum\nolimits_j \alpha_j \cdot Y_j(k+1 \mid k),$$

where they must correspond to relation $\sum\nolimits_j \alpha_j = 1$. Summation is performed for all j extrapolation variants.

Values α_j are calculated from a minimum value of extrapolation error:

$$\sigma^2\left[Y_\Sigma(k+1 \mid k)\right] = \\ = \left[\sum\nolimits_j \alpha_j \cdot Y_j(k+1 \mid k) - Y(k+1)\right]^2.$$



Frequency detector output signal and the histogram of the signal; the repaired signal at making a solution for circuit output

For linear and quadric extrapolations:

$$Y(k+1\,|\,k)=\alpha_1\cdot Y_1(k+1\,|\,k)+\alpha_2\cdot Y_2(k+1\,|\,k),$$

$$\sigma^2\left[Y_\Sigma(k+1\,|\,k)\right]=$$

$$=\left[\alpha_1\cdot Y_1(k+1\,|\,k)+\alpha_2\cdot Y_2(k+1\,|\,k)-Y(k+1)\right]^2.$$

Minimum value of the relation above is obtained for the following values of coefficients:

$$\alpha_1=\frac{\sigma^2\left[Y_2(k+1\,|\,k)\right]}{\left(\sigma^2\left[Y_1(k+1\,|\,k)\right]+\sigma^2\left[Y_2(k+1\,|\,k)\right]\right)},$$

$$\alpha_2=\frac{\sigma^2\left[Y_1(k+1\,|\,k)\right]}{\left(\sigma^2\left[Y_1(k+1\,|\,k)\right]+\sigma^2\left[Y_2(k+1\,|\,k)\right]\right)}.$$

Therefore:

$$Y_\Sigma(k+1\,|\,k)=\frac{\sigma^2\left[Y_2(k+1\,|\,k)\right]\cdot Y_1(k+1\,|\,k)+\sigma^2\left[Y_1(k+1\,|\,k)\right]\cdot Y_2(k+1\,|\,k)}{\sigma^2\left[Y_1(k+1\,|\,k)\right]+\sigma^2\left[Y_2(k+1\,|\,k)\right]}.$$

Using the belief ratio, an output value of extrapolated parameter is calculated using the following formula:

$$Y_{\text{вых}}(k+1\,|\,k)=\left[1-W(k)\right]\times$$

$$\times Y_\Sigma(k+1\,|\,k)+W(k)\cdot Y(k),$$

where the belief ratio is such that $0\le W(k)\le 1$. So, if the belief ratio is high (normal tracking conditions), then the extrapolation of the device relies more on the current value of parameter $Y(k)$. Otherwise, the parameter is predicted by its values which were before the decrease of the belief ratio. The result of the experiments shows that the properties of this prediction procedure are the same as those of the Kalman filtering.

The results for the application of the described procedure can be stated briefly as:

1. The procedure and algorithm are developed for the correction of the average level of frequency-shift keyed signal carrier with a histogram procedure beyond frequency detector, without the usage of FFT or LF, which provides high noise immunity and performance.

2. The estimation of efficiency of the procedure and algorithm was done using real data flow. The estimation showed a considerable decrease in the number of computing operations during the correction of the carrier frequency average level and durability of the algorithm to noise. The dependence of $\hat{A}_H(\Delta f)$ from carrier frequency mismatch Δf is linear.

The estimation of the carrier frequency level does not depends on the number of “0” and “1” chars in data flow and does not require the setting of special messages or markers for the frequency level determination. The procedure allows the obtaining of unbiased estimates of the average signal level beyond the frequency detector when the carrier frequency deviates.

The procedure and algorithm of the CFR shows durability, linearity, and precision of the proposed estimation carrier level histogram procedure for solving the received char meaning.

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MAGNETIZATION OF MULTILAYER FERROMAGNETIC FILM WITH A NONMAGNETIC INTERLAYER

The magnetization of magnetic film, consisting out of two ferromagnetic layers with a nonmagnetic interlayer applied to antiferromagnetic substrate is considered in this paper.

Keywords: ferromagnetic, antiferromagnetic, interlayer interaction.

Currently, the issue we consider is of great significance because there is an international interest in multilayer magnetic systems. Such systems are used in magnetoresistive sensors, components of magnetic send-receive, spin diodes. The magnetization of a multilayer magnetic system consisting of two ferromagnetic layers with a nonmagnetic interlayer applied to antiferromagnetic substrate is considered in the presented paper. The theoretical model used for the investigation of the stated process had been introduced in paper [1]. Inhomogeneous distribution takes place in this system because of substrate influence. This is why we use a stated model.

Physical properties of the film are defined by its boundaries. A bilayer system with the ferromagnetic-on-antiferromagnetic-substrate type is investigated in research paper [1] where the boundary condition of clamped magnetization vector type had been considered.

In paper [2] it had been demonstrated that the magnetization process of such a system has a threshold type. The author [2] points out an analogue between the magnetization process and the bending of elastic rod considered in paper [3]. It is also necessary to refer to paper [4].

Later the boundary condition of the clamped vector type was replaced by condition of elastically restrained vector type by introducing an effective interlayer at the ferromagnetic-antiferromagnetic boundary [5]. In later research of bilayer ferromagnetic film, the layers of which were rigidly bond with an antiferromagnetic substrate was overlooked in [6]; using an analog of a two-part elastic shank clamped at one edge and free at the other [7].

Today the presence of a nonmagnetic interlayer in ferromagnetic systems and its influence on threshold fields and the distribution of magnetization aren't being studied.

The potential energy of the magnetic system is given as expression [8]:

$$F\left(\mathbf{M}, \frac{\partial M_i}{\partial x_k}\right) = \frac{1}{2}\alpha_{ik}\frac{\partial \mathbf{M}}{\partial x_i}\frac{\partial \mathbf{M}}{\partial x_k} + w_a(\mathbf{M}) + f\left(M^2\right), \quad (1)$$

where, the first summand represents the quadratic form of derivatives, $w_a(\mathbf{M})$ is the magnetic anisotropy energy, $f(M^2)$ is some function of M^2. We only overlook isotropic ferromagnetic films where magnetization inhomogeneous is present along thickness of the object. Thereby, the second summand turns into zero and the first summand turns into the following expression:

$$\frac{1}{2}\alpha\left(\frac{d\mathbf{M}}{dz}\right)^2.$$

Axis z is directed perpendicularly to the layers. A variation of the third summand results in zero because the magnetization vector length doesn't change; therefore we shall not consider it. Thereby, the energy of the ferromagnetic layer may be represented as:

$$U = \int_0^{d_1}\left(\frac{1}{2}\alpha_1\left(\frac{d\mathbf{M}_1}{dz}\right)^2 - \mathbf{M}_1\mathbf{H}\right)dz + \int_{d_1+d_s}^{d_1+d_s+d_2}\left(\frac{1}{2}\alpha_1\left(\frac{d\mathbf{M}_1}{dz}\right)^2 - \mathbf{M}_1\mathbf{H}\right)dz, \quad (2)$$

where d_1, d_2 are the thicknesses, $\mathbf{M}_1$, $\mathbf{M}_2$ are the magnetization densities, α_1, α_2 are the exchange constants of first and second layers respectively; d_s is the interlayer thickness, $\mathbf{H}$ is the applied magnetic field.

The energy of interlayer is given in the expression:

$$U_s = -\frac{\alpha_s}{d_s}\mathbf{M}_1\mathbf{M}_2, \quad (3)$$

where α_s is the interlayer exchange constant.