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SYNTHESIS OF DIGITAL FILTER STRUCTURES FOR DETERMINING VOLTAGE PARAMETERS

Ushkarenko O. O., Malakhova N. G. (maestrotees@gmail.com, nadiamalahova@gmail.com)
Admiral Makarov National University of Shipbuilding (Ukraine)

In the paper, the synthesis of digital filter structures for determining voltage parameters is considered. The relevance of the work is due to the need to improve the digital signal processing subsystems as part of instrumentation to improve their accuracy and ensure real-time operation. For the synthesis of digital filters, a method for describing their structures was used. Used method consists in the formation of a graphic-analytical form of describing the procedure for processing input arguments. In the conclusions, the advantages of the obtained structures of digital filters are given and the practical value of the results is indicated.

Nowadays, in ship electric power systems (SEPS), much attention is paid to the power quality control. Power quality is characterized by parameters such as harmonic distortion, reactive power availability, load unbalance [1] etc. The supply voltage must have a sinusoidal form with a constant value of amplitude and frequency [2]. However, due to the presence of a non-zero impedance of the power source, different loads in a three-phase system, voltage unbalance may occur. The review and analysis of the power quality in SEPS carried out in [3] confirms the relevance of the problem of controlling the power quality. At the same time, an unresolved problem of the influence of voltage frequency fluctuations on the measurement accuracy was also noted. Therefore, an important task is to develop the structure of the digital signal processing subsystem, which would minimize the influence of input voltage fluctuations on the measurement accuracy. In [4] it is noted that not all manufacturers of equipment for measuring power quality follow the standards when developing their devices. In addition, as noted in [5], if the sampling frequency of the signal does not match the frequency of the mains voltage, the signals are digitized incoherently. The solution proposed in [5] and obtained in analytical form is characterized by high computational costs. Therefore, the problem of synthesizing a digital structure for calculating the mean and root-mean-square values of a deterministic periodic signal at the optimal speed of a discrete system is important.

The arithmetic mean value of an alternating signal with a period T is calculated by the formula [6]:

$$u_{avg} = \frac{1}{T}\int_0^T |u(t)|dt. \qquad (1)$$

The expression for calculating the average value of a signal can be written in discrete form as follows:

$$Y(kT_s) = \sum_{n=0}^{N-1} h \cdot X\left[(k-n)T_s\right],$$

где $Y = u_{avg}$, $X = |u|$, $\frac{1}{N} = h$, $N = \frac{T}{2 \cdot T_s}$.

This equation describes a linear FIR filter impulse response of the order $N-1$. Expression (1) can be written in the form of an analytical expression shown in Fig. 1.

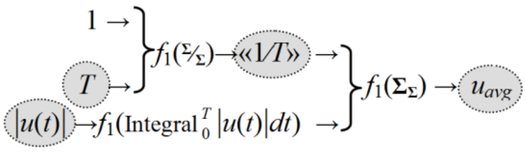

Fig. 1. The expression for calculating the average value of a signal

The expression for calculating the average value of a signal can be presented in a discrete form and described with a formula:

$$u_{avg}(t) = \frac{1}{N}\sum_{n=0}^{N-1}\left|u(t - nT_s)\right|. \quad (2)$$

Expression (2) can be written in the form of an analytical expression presented in Fig. 2.

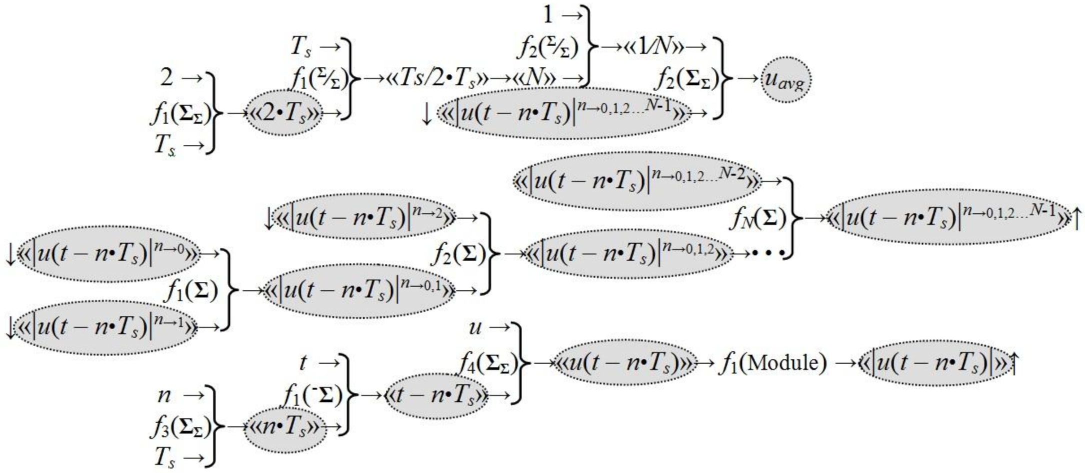

Fig. 2. Digital filter structure for calculating the average value of a signal

To obtain the final resultant argument $Y(kT_s)$ of the expression, it is necessary to perform the transformation of the input arguments in accordance with the graphical-analytical expression shown in Fig. 3.

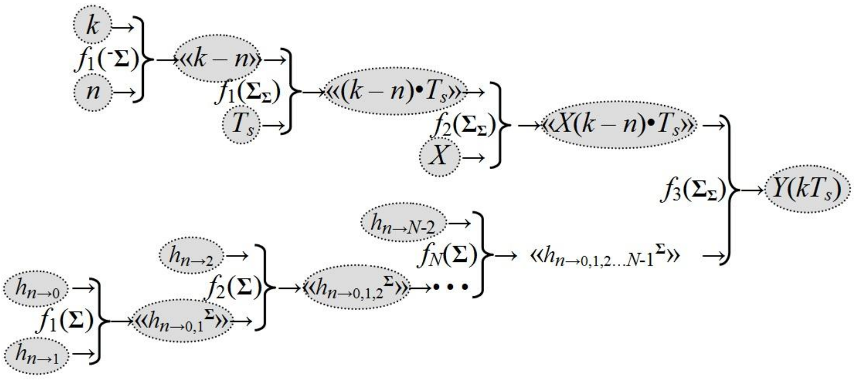

Fig. 3. The procedure of transformation of the FIR-filter input arguments

The presented graphic-analytical expression describes a linear FIR-filter with an impulse response of finite duration $N-1$.

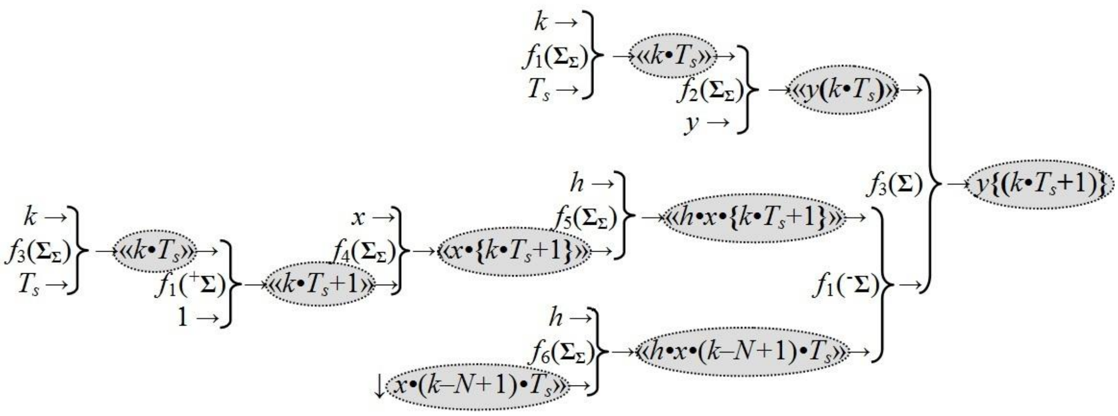

Fig. 4. Graphic-analytical expression of a linear FIR-filter

To calculate the next output sample of the optimized digital filter, it is necessary to perform 3 operations of addition and one operation of multiplication, instead of N operations of addition and N operations of multiplication. By including additional functional blocks A^2 and $\sqrt{A}$, the considered structure of a digital filter with equal weighting factors for calculating the mean value of a signal (voltage) can be used to calculate the root mean square value of the input signal.

The structure of the digital filter for calculating the mean value of the input discrete signal, considered in this work, was implemented in the C programming language. Also, a software implementation of the basic structure of the filter and its optimized structure was carried out for a comparative analysis of their effectiveness for various values of the filter order. In this experiment, a step function was applied to the inputs of the filters to determine the value of the time interval required by the digital filters to perform all calculations and generate the output value. The experiment was carried out for different values of the digital filters orders – 16, 64, 256 and 1024. It was found that the efficiency of the optimized digital filter is nonlinear and depends on the filter order. For small values of the digital filter orders, their performance is almost the same. However, with an increase in the order of filters, the efficiency of a filter with an optimized structure increases sharply. This is important because the considered algorithm is intended to be implemented in 8-bit RISC microcontrollers, which are widely used in control and automation systems.

Conclusions. The paper considers an improved method for describing the structures of digital filters by forming a graphical-analytical form of describing the procedure of input arguments converting by means of functional structures. This approach makes it possible to increase the information content of mathematical models of digital signal processing subsystems and to analyze the system by multilevel decomposition. The carried out research is a supplement to work [7] in relation to digital systems. Increasing the sampling frequency in the optimized filter structure does not lead to an increase in the number of arithmetic operations of addition and multiplication, which is an advantage of the proposed filter structure compared to similar ones. The use of microprocessor technology and software implementation of calculation algorithms makes it possible to eliminate this phenomenon by adjusting the length of the digital filter delay line depending on the frequency of the input signal. This makes the developed system the property of adaptability, which similar systems do not have. The practical value of the obtained results is in the possibility of synthesizing optimized structures of digital filters. The proposed method was used to optimize the structure of the DSP system to determine the mean and root mean square voltage values.

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