SYSTEM FOR DIGITAL PROCESSING OF MULTIDIMENSIONAL SIGNALS

Dmitri CALUGARI, Viorica SUDACEVSCHI, Victor ABABII, Dimitri BORDIAN

Technical University of Moldova

Victor.ababii@calc.utm.md

Abstract — **In this research paper, the outcomes of a system synthesis for digital processing of multidimensional signals are indicated. As a result of the design, a block and functional diagram and a time diagram containing a sequence of signal conversion and synchronization have been obtained.**

Index Terms — **multidimensional processes, multidimensional signals, data acquisition, time synchronization, temporal interpolation.**

I. INTRODUCTION

The world surrounding us can be represented in the form of a multidimensional process, where any dimension is considered in a multidimensional coordinate system or multiply-connected parameters (signals). The most common fields of science in which multidimensional processes or multiply-connected parameters (signals) are investigated are biology, economics and sociology. A classic example of the study of multidimensional signals is the process of input, processing and storage of brain signals [1, p. 2], where a multichannel method of parallel input and processing of multidimensional signals is considered.

In the research paper [3] the necessity, basic methods and models for digital processing of multidimensional signals, such as: digital filtering theory, discrete Fourier and Z-transform, two-dimensional recursive and non-recursive discrete filters are described.

Additionally, the main methods of pre-processing, multiplexing of analog signals, methods for measuring electrical and non-electrical parameters, methods of isolation and signal conditioning and analog-to-digital conversion of multidimensional signals were considered in [4].

The main task for input and processing of multidimensional signals is spatial and temporal synchronization. These problems were considered in the research works [2, 5, 6], where the authors concentrate on the processing of human EEG signals, which can serve as a prototype for the study of other multidimensional processes.

One of the methods of spatial and temporal synchronization is interpolation [7]. By means of interpolation, it is possible to obtain the exact values for the corresponding instants of time, or for the corresponding spatial locations with given coordinates.

A special case of digital processing of multidimensional signals was suggested in works [8, 9], where methods for evaluating the functionality and correctness of printed circuit boards are considered.

II. PROBLEM STATEMENT FOR THE SYNTHESIS OF THE PARALLEL DATA ACQUISITION SYSTEM FOR THE ANALYSIS OF MULTIDIMENSIONAL SIGNALS

Suppose that in a three-dimensional space (Figure 1) a multidimensional process is defined that generates a set of multiple signals with amplitudes $A = \{a_1, a_2, ... a_N\}$ (1):

$$a_i = f_i\left(t, a_j, \forall j = \overline{1, N}, j \neq i\right),$$

where a_i - amplitude of a signal at a point with coordinates $O_i = (x_i, y_i, z_i)$; f_i - function that determines the dynamics of the signal amplitude a_i depending on the time t and the neighbouring signals $a_j, \forall j = \overline{1, N}, j \neq i$.
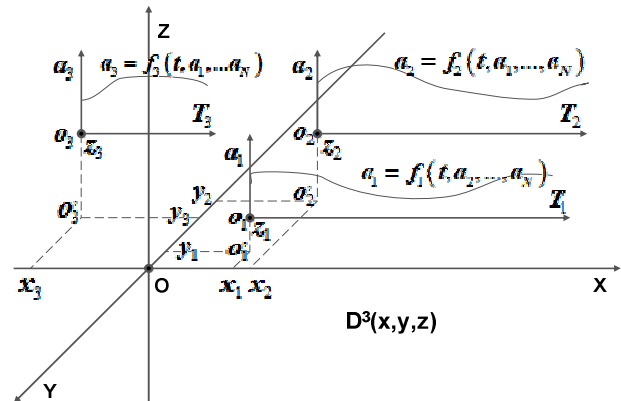

Figure 1. Three-dimensional space with the signals of the process state

The aim of this paper is to design a system for parallel input of multidimensional signals (Figure 1), their temporal interpolation followed by spatial and temporal synchronization for analysis.

III. BLOCK DIAGRAM OF THE PARALLEL DATA ACQUISITION SYSTEM FOR THE ANALYSIS OF MULTIDIMENSIONAL SIGNALS

The block diagram of the parallel data acquisition system for multivariate signal analysis is presented in

Figure 2, where: ENV - the space under study; DC - signals pre-processing unit; $DAI / FPGA$ - interface and digital data processing unit; PC - Computer for the configuration of the unit, $DAI / FPGA$ - data input through a standard interface USB and data analysis.
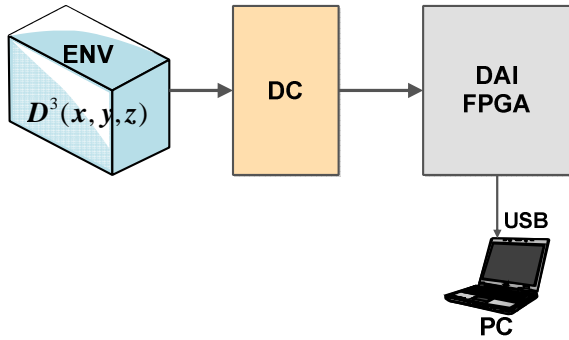

Figure 2. Block diagram of a parallel data acquisition system for the analysis of multidimensional signals

IV. FUNCTIONAL DIAGRAM OF THE PARALLEL DATA ACQUISITION SYSTEM

The functional diagram of the parallel data acquisition system contains homogeneous channels and is represented in Figure 3. Each channel processes one state signal $A = \{a_1, a_2, ... a_N\}$ and includes the following functional blocks:

$s_i, \forall i = \overline{1, N}$ - a number of sensors that convert state signals into electrical signals $u_i, \forall i = \overline{1, N}$;

$\dfrac{du_i}{dt}, \forall i = \overline{1, N}$ - time differentiation blocks that calculate the rate of change of the input signal;

$\overset{\bullet}{u_i}, \forall i = \overline{1, N}$ - results of differentiation;

$\displaystyle\int_{T_i}^{T_{\Delta D}} \left(\overset{\bullet}{u_i} \right) dt, \forall i = \overline{1, N}$ - integration blocks, perform integration over a time interval $\left[T_i, T_{\Delta D} \right]$, where T_i - time of integration end, until the results of integration are achieved $u_i^I \geq u_{\Delta D}^+$ or $u_i^I \leq u_{\Delta D}^-$;

$u_i^I, \forall i = \overline{1, N}$ - results of integration;

$\Delta D_i = \begin{cases} + \left| u_i^I \geq u_{\Delta D}^+ \right. \\ 0 \left| u_{\Delta D}^+ > u_i^I > u_{\Delta D}^- \right. \\ - \left| u_i^I \leq u_{\Delta D}^- \right. \end{cases}, \forall i = \overline{1, N}$ -

comparing blocks, perform a comparison of the integration result u_i^I with a threshold voltage: $u_{\Delta D}^+$ - in case of a positive integration result and $u_{\Delta D}^-$ – in case of a negative integration result;

$CT(u_i), \forall i = \overline{1, N}$ - counters of the number of pulses, count the number of times the condition for comparing the result of integration with the threshold voltages is satisfied. Counters $CT(u_i)$ generate addresses $Adr(a_i), \forall i = \overline{1, N}$ for the operative memory $RAM(a_i), \forall i = \overline{1, N}$, in which the current time of execution of the comparison condition and the bits of the sign of integration $(+)$ or $(-)$ are stored;

$WR_i, \forall i = \overline{1, N}$ - signals for synchronization of data recording in memory - $RAM(a_i), \forall i = \overline{1, N}$;

$D_M \div D_0$ - the least significant bits of data that contain the current time;

D_{M+2} - the highest data bit that contains the value of the "+" signal generated by the comparison unit;

D_{M+1} - data position bit $M+1$, which contains the value of the "-" signal generated by the comparison unit;

$RST(Int_i), \forall i = \overline{1, N}$, reset signals of the corresponding integrator to start a new integration cycle;
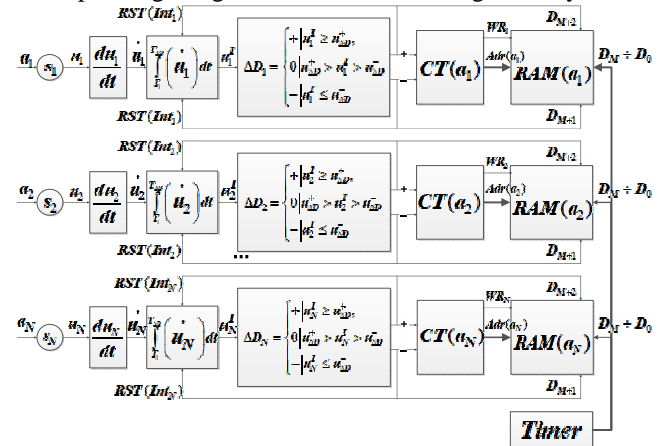

Figure 3. Functional diagram of the parallel data acquisition system

The process of the parallel data acquisition system is explained by the time diagram, which is presented in Figure 4.

The signal CLK increments the timer $Timer$, which counts the system time with intervals ΔT. The graphic u_i represents the signal received from the sensor and is proportional to the amplitude of the measured state parameter a_i. The diagram shows the integration process and the integrator initialization process. Depending on the state of the integrator, signals ΔD_i are generated that determine the step of sampling the input signal u_i and the sign of the integration result. With a positive sign of the integration result, a $(+)$ signal is generated, with a negative sign of the integration result, a $(-)$ signal is generated. The initialization of the corresponding integrator takes place by a signal $RST(Int_i) = (+) \oplus (-)$. At the same time, the

counter $CT(a_i)$ of the corresponding channel is incremented $Inc(CT_i)$. The counter $CT(a_i)$ generates a memory address $Adr(RAM_i)$. The signal WR_i at the specified address $Adr(RAM_i)$ records the contents of the timer $Timer$ in the digits $D_M \div D_0$, the $(-)$ value of the signal in the bit D_{M+1}, and the $(+)$ value of the signal in the bit D_{M+2}.

In this way, in the memory $RAM(a_i)$ of each channel, control points containing the direction of the change in the level of the input signal and the current system time in which there was a transition through the sampling step are accumulated.
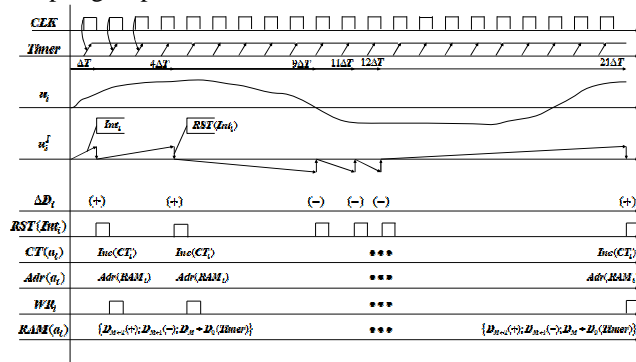

Figure 4. Time diagram of the functioning of one channel of the system for data acquisition

V. DATA RECOVERY BY TEMPORAL INTERPOLATION METHOD

An example of data recovery, for one channel, by the method of linear interpolation [7] by time is presented in Figure 5, where:

OTu_i - coordinate system consisting of: OT - time coordinates with a sampling step ΔT and Ou_i - coordinates of the amplitude of the signal with a sampling step Δu_i ;

$u_i = g\left(t, a_j, \forall j = \overline{1,N}\right)$ - the initial analog signal, intended for input and analysis;

$u_i^* = g^*\left(t^*\right)$ - reconstructed signal, by the method of linear interpolation, which forms a set of rectilinear segments $O, p_1, p_2, p_3, \ldots$;

$\{d_7; d_6; d_5 d_4 d_3 d_2 d_1 d_0\}$ - data received from memory $RAM(a_i)$ to restore the signal, where: $d_7 = (+)$, $d_6 = (-)$ and $d_5 \div d_0 = (Timer)$.

To more accurately calculate the amplitude of the reconstructed signal u_i^* and time synchronization of multidimensional signals, in the segment $\left[p_1\left(3\Delta T, \Delta u_i\right), p_2\left(10\Delta T, 2\Delta u_i\right)\right]$ an example of dividing the time interval $\left[3\Delta T, 10\Delta T\right]$ into a set of sub-intervals of the duration τ is illustrated.
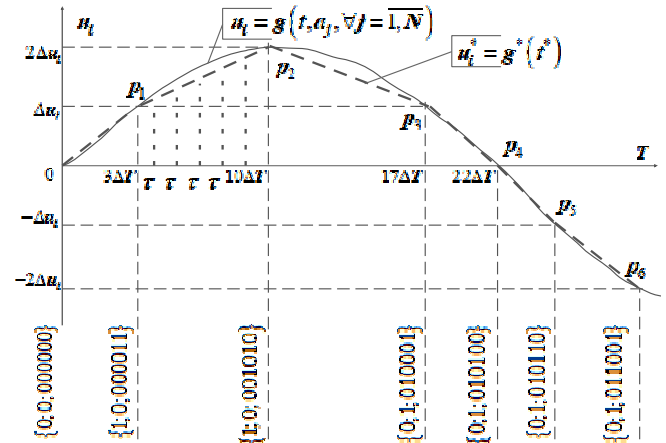

Figure 5. Data recovery for one channel by temporal interpolation

CONCLUSIONS

As a result of the synthesis of a parallel data acquisition system for multidimensional signal analysis, there were obtained a block diagram, a functional diagram and a time diagram which represents the sequence of signal conversion and synchronization. An example of data recovery by the method of linear interpolation is presented to provide the possibility of time synchronization between signals.

The signal conversion process consists in determining the sampling step by time and amplitude, calculating the rate of change of the amplitude of the input signal, and calculating control points containing the direction of the change in the input signal and the current system time. The received data is stored in the operative memory for subsequent reading and digital processing on a computer basis.

In this work, the following further actions are envisaged: research and design of technical and software automation tools for the synthesis of a parallel data acquisition system for the analysis of multidimensional signals.

BIBLIOGRAPHY

1. Kida T., Tanaka E. and Kakigi R. Multi-Dimensional Dynamics of Human Electromagnetic Brain Activity. Front. Hum. Neurosci. 9:713. 2016. doi: 10.3389/fnhum.2015.00713.

2. Prochzka A., Bartoov V., and O. Vyata O. Multi-channel signal segmentation and classification. *In Proceedings of the 8th IASTED International Conference on Visualization, Imaging and Image Processing. September 1 – 3, 2008, Palma de Mallorca, Spain.* ISBN: 978-0-88986-759-8. (Доступен на: http://www.actapress.com/Abstract.aspx?paperId=339 36).

3. Даджион Д., Мерсеро Р. Цифровая обработка многомерных сигналов: Пер. с англ.—М.: Мир, 1988.— 488 с.

4. Data Acquisition Handbook. A Reference for DAQ and Analog & Digital Signal Conditioning. Third Edition. Mesurement Computing Corporation USA 2012. – 145 p. (Доступен на: http://www.mccdaq.com/pdfs/anpdf/Data-Acquisition-Handbook.pdf).

5. Фингелькурц А. Пространственно-временная организация сегментной структуры ЭЭГ человека. Дисс. раб., МГУ, Москва, 1998, 273 стр.

6. Коробейникова И. Связь пространственной синхронизации биопотенциалов тета-диапазона ЭЭГ человека с разной успешностью выполнения зрительно-пространственных задач. Физиология человека, 37 (5), 2011, стр. 26-34. ISSN: 0131-1646.

7. Шарый С. Курс вычислительных методов. Институт вычислительных технологий СО РАН, Новосибирск, 2017, 574 с.

8. Ababii V., Sudacevschi V., Calugari D., Bordian D. Система цифровой обработки многомерных сигналов для оценки функциональности печатных плат. *INTERNATIONAL INNOVATION RESEARCH, Сборник статей VIII Международной научно-практической конференции, Пенза, 27 апреля 2017 г.*, стр. 112-115, ISBN: 978-5-9500235-0-7. (РИНЦ: https://elibrary.ru/item.asp?id=29050070).

9. Калугарь Д., Абабий В., Судачевски, В. Цифровая обработка многомерных сигналов для оценки корректности печатных плат. *Прикладні науково-технічні дослідження : матеріали міжнар. наук.-прак. конф., 5-7 квіт. 2017р. – Івано-Франківськ : Симфонія форте, 2017*. стр. 94, ISBN: 978-966-284-110-7.