Real-time fast Fourier transform

P S Ivanova, K Y Muradyan, A O Tolokonsky

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
E-mail: PSIvanova@mephi.ru

Abstract. The paper presents a method of implementation of fast Fourier transform in real-time data processing and measurement systems. The method is based on software and hardware package «UMIKON», supporting input-output drivers. Classic Cooley and Tukey algorithm apply to real-time data vector, which formed by successive shift after every clock cycle time. This approach to data processing in real-time allows reaching high access time in information measurement systems when analyzing dynamic processes.

1. Introduction

Analog signal conversion to digital form and subsequent data processing has a wide application in different branches of science and technology. Digital signal processing has great importance in monitoring, control and production control [1].

Discrete Fourier transform, as a one of an all-purpose method, allows using frequency distribution of source data. However discrete Fourier transform requires significant computational efforts, whilst some engineering problems demand fast calculation. There are various fast algorithms [2] with less computational complexity. For instance, Cooley and Tukey algorithm produces a result with complexity $O(Nlog(N))$ against $O(N^2)$, where N is a number of counts.

Particular engineering problem is software and hardware implementation of real-time fast Fourier transform, which is considered in the current work. Development of real-time fast Fourier transform is necessary for different engineering applications, particularly for creating a system for diagnosing and predicting transition heat exchange regimes. A temperature of the heat transfer surface is always experienced stochastic fluctuations, analyzing the distribution of that valuable information about the heat exchange regime can be obtained. Contributions [4, 5] report that spectral analysis of temperature fluctuations obtained by Fourier transform can be used as a base for the diagnostic of changing heat exchange regimes. Transient heat-exchange regimes have a relatively small characteristic time (from 1 ms to 10 s). In terms of measurement and industrial control systems, it is necessary to provide data transmission and implementation of real-time fast Fourier transform in order to control and diagnose such processes.

The problem could be solved using a multilevel industrial control system. A low-level system includes controllers ensuring data preprocessing. Processing station and database servers included in SCADA-system (Supervisory Control and Data Acquisition system) provide information acquisition, analysis, and visualization.

The aim of this work is to develop software and hardware instruments realizing real-time fast Fourier transform for transient heat exchange regimes diagnostic system. Results could be applied to any system requiring high time performances in real-time information and measurement system for dynamic processes study.

Journal of Physics: Conference Series **1439** (2020) 012049 doi:10.1088/1742-6596/1439/1/012049

2. Software and hardware package for fast Fourier transform implementation

The main objective of the software and hardware complex is instrumentality formation for real-time information and measurement system. In other words, the interrogation of measurement sensors through communication device with the control object and issuance of control action occurs every fixed time interval. Moreover, the time interval value is not significant.

The method of implementation of real-time fast Fourier transform is based on software and hardware package «UMIKON» [6]. SCADA-system included in «UMIKON» supports input-output drivers and built-in programming language. The use of the Input-output driver simplifies the data exchange process thereby allowing to reduce a delay at data transmission (Figure 1).

Figure 1. The scheme of organization of data exchange using input-output drivers

One of the most significant functionality of SCADA-system within the framework of solving this task is an input-output subsystem. There are two main ways of data exchange with devices: the use of OPS-server (Open Platform Communication server) or input-output driver usage.

OPC-server is the data source for OPC-clients. The data exchange process in this case can be illustrated as it is shown in Figure 2. However, this method of data exchange does not allow to realize real-time fast Fourier transform since it has significant delays due to the presence of intermediate data link. Therefore, the data exchange method with use of input-output drivers (Fig. 1) was used.

Figure 2. The scheme of organization of data exchange using OPS

Low-level and SCADA system software is multi-platform distributed scalable instruments, supporting real-time clock cycle time from 1 ms. It covers all hierarchy levels from controller and analog module to archiving and calculation of different sensor data for a period of up to several years. Besides, basic software has customization tools for controllers and individual modules allowing them to perform additional functions in real-time at the same time with background data transmission processes.

Described features of used software and hardware package allow implementing such data processing operation as fast Fourier transform at several hierarchical levels of the system at once. It leads to the necessity of choosing a hierarchical level at which the real-time discrete Fourier transform is most efficient. Analysis of instruments and implementation tools of each hierarchical level of industrial control system allows concluding that real-time fast Fourier transform implementation is the most optimal in SCADA-system. Such a choice of hierarchical level is due to the data transmission method from low-level to SCADA-system without delay and with saving real-time regime on that level. Mentioned benefits allow simplifying the work with big data upon implementation of fast Fourier transform.

Summing up, implementation of the real-time fast Fourier transform is executed in the SCADA-system of software and hardware package «UMIKON».

3. Real-time fast Fourier transform implementation

The industrial programming system is the complex of procedures executed according to a special cyclic time-sharing algorithm. It is proposed to develop a method that uses real-time vector and matrix data processing in the present paper.

In order to obtain a data vector in real-time, a copy operation is performed, after which the data vector is copied with a shift (Figure 3). The lock cycle time of the real-time system is 100 ms. The result is a vector consisting of elements updated 10 times per second.

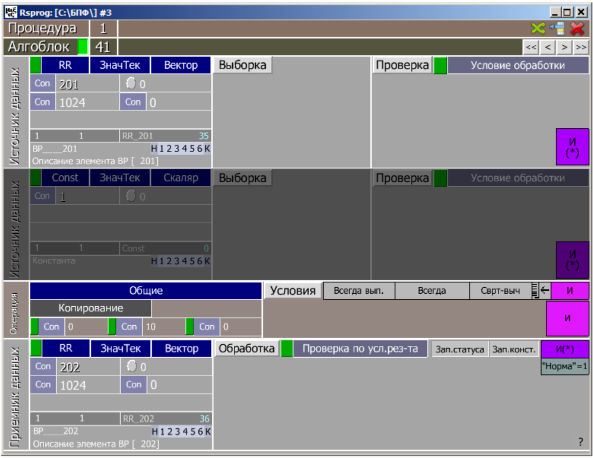

Figure 3. Copy operation with a shift of the input vector for fast Fourier transform

Fast Fourier transform expression can be written as follows:

$$S_d(k) = \sum_{n=0}^{N-1} s(n) \cdot exp\left(-j \cdot \frac{2\pi}{N} \cdot n \cdot k\right), k = 0 \dots N-1 \tag{1}$$

where $S_d(k)$ is the discrete signal, N is the number of elements and $s(n)$ is the source data.

The classical Cooley and Tukey algorithm [3] is used in the work. is used. Source sequence $s(n)$ is divided into to two subsequences $s_0(m)$ and $s_1(m)$, where m = 0 … N/2 – 1, so, that $s_0(m)$ includes samples with even indexes and $s_1(m)$ includes samples with odd indexes. Therefore, the discrete Fourier transform is expressed in the following form:

$$S_0(k) = \sum_{m=0}^{\frac{N}{2}-1} s_0(m) \cdot exp\left(-j \cdot \frac{2\pi}{N} \cdot m \cdot k\right), k = 0 \dots \frac{N}{2} - 1 \tag{2}$$

$$S_1(k) = \sum_{m=0}^{\frac{N}{2}-1} s_1(m) \cdot exp\left(-j \cdot \frac{2\pi}{N} \cdot m \cdot k\right), k = 0 \dots \frac{N}{2} - 1 \tag{3}$$

Each of the subsequences is divided into even and odd again. For $N = 2^L$ samples it is performed $L - 1$ division operations and after than spectrum is united by L operations. When the data vector and subsequences division has been done, the fast Fourier transform is realized by math operation (1).

It should be mentioned, that the described algorithm of discrete Fourier transform is applied to data vector with a fixed number of elements. The data vector is changed every clock cycle time by the successive shift of elements and substitution of the new data. The proposed approach of the dynamically changing data processing allows using fast Fourier transform and monitor data spectrum changes in real-time.

4. Conclusion

The approach of implementation of the real-time fast Fourier transform using the Cooley and Tukey algorithm [3] is proposed. The algorithm is implemented in the SCADA-system of software and hardware package «UMIKON».

The distinctive feature of the algorithm implementation is real-time data processing. The essence of the method is the presentation of elementary sets of numbers located in the computer memory or in the central processor module as a dynamically changed vector, the elements of which are updated with the clock cycle time, whilst the other actions also can be performed on this sets. Vector data is important for the implementation of high-speed numerical processing since it is possible to specify an operation by one command for a lot of data and to activate various mechanisms of parallel processing in a central processor. Data vector change with every clock cycle time by successive shift.

The proposed approach could be used in highly effective information measurement systems for real-time analysis of dynamic processes. In particular, it could be applied to the implementation of a system for diagnosing and predicting transition heat-exchange regimes based on spectrum analysis of heat-transfer surface temperature fluctuation [5].

References

[1] Huang N E, Shen Z, Long S R, Wu M C, Shih H H, Zheng Q, Yen N-C, Tung C C and Liu H H 1998 *Proc. R. Soc. Lond. A.* **454** 1971

[2] Cooley J W, Lewis, Peter A W, Welch, Peyer D 1965. *Historical notes on the fast Fourier transform*. **15** (2) 76-79

[3] Cooley J W and Tukey J W 1965 *Mathematics of Computation* **19** (30) 297-301

[4] Deev V I, Kutsenko K V, Lavrukhin A A, Maslov Y A and Delov M I 2014 *Thermal Engineering (English translation of Teploenergetika)* **61** (8) 590-593

[5] Balakin B V, Delov M I, Kutsenko K V, Lavrukhin A A, Laouar S, Litvintsova Y E, Marchenko A S, Maslov Y A 2017 *Thermal Science and Engineering Progress* 4 2019-222

[6] Lebedev V O 2012. *SHC is new horizont*. *Industrial automation* **1** 44-46 (in Russian)