Development problem analysis of correlation leak detector's software

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Abstract. In the article, the practical application and the structure of the correlation leak detectors` software is studied and the task of its designing is analyzed. In the first part of the research paper, the expediency of the facilities development of correlation leak detectors for the following operating efficiency of public utilities exploitation is shown. The analysis of the functional structure of correlation leak detectors is conducted and its program software tasks are defined. In the second part of the research paper some development steps of the software package – requirement forming, program structure definition and software concept creation – are examined in the context of the usage experience of the hardware-software prototype of correlation leak detector.

1. Introduction

Over a number of years an important task for the national economy is hausing and utility infrustructure maintaince and development, the key component of which is water supply networks. This fact is explained by growing people`s demand for comfort and rational use of time.

The raise of service quality, given to citizens, is impossible without the communal infrastructure modernization and the improvement of orginisational and, most of all, technical service equipment. In the present paper the issue of improving of correlation leak detection complexes charasteristics by means of its software development is anylised. The exploitability of the field above is defined by the fact that correlation technique of leak detection implies the applcation of complex mathematical apparatus of data digital processing, which to a large extent determines the operational efficiency of leak detection complexes.

Thus, the task analysis of the leak detection complexes` sofware is performed in the paper and the concept of the original software solution is offered.

2. Application of hardware-software leak detectors

Due to its massive scale, the efficient exploitation of available pipeline infrastructure is a technically hard task. Thus, for example, the spread of street utility water supply, water drain and heating network in all populated areas of Russia is more than 600 thous. km in total [1]. The situation is also aggravated by networks' bad conditions; by 2015 about 40% (250 thous. km.) of water pipelines of different profiles had exceeded its safe and usage date and had to be replaced [1].

It should be mentioned that despite the set of organizational-technical measures being implemented by the Russian government, aimed at the number of emergency, decreasing, its amount remains extremely high (more than 500 thous. registered cases over a period of 2013-2015) [1]. Under present circumstances, immediate emergency localization and liquidation of its consequences are one of the essential condition of infrastructure`s efficient exploitation [2]. Early failure detection of a leak in subsurface pipelines and its positioning data definition demands the usage of some special technical equipment [2, 3].

The hardware-software correlation leak detection complexes, better known as correlators, are one of the operating control tools of water supply technical conditions which work well in practice. The operating principle of such devices is based on the method developed [4] and got a widespread use in the 70-80s of the last century [5, 6]. The point of the method can be described as follows. When the liquid flows out of the pipe under the pressure, some acoustic waves start to originate through the opening. At the same velocity, they scatter along the pipeline in both directions. The waves are received by a pair of piezoelectric transducers located at opposite ends of the surveyed pipe linear section. The report about the leak`s location is judged according to the result of the correlation processing of signals coming from the sensors [4].

In accordance with the application conditions, correlators are portable devices consisting of various functional parts. Despite the fact that the actual correlators configuration can vary significantly depending on a manufacturer [7], one can describe their typical functional structure. Figure 1 shows a generalized functional scheme of a leak detection complex.

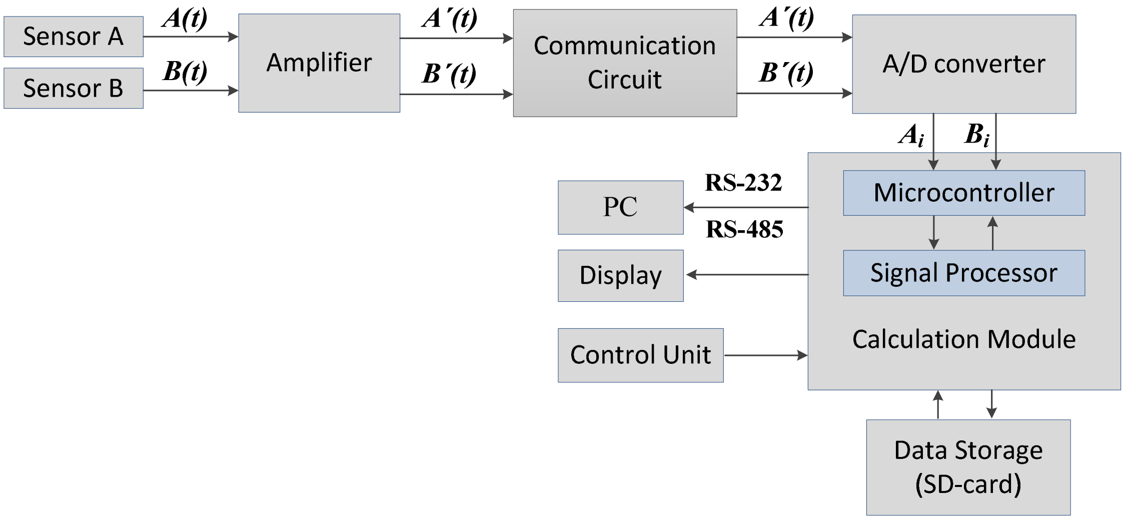

Figure 1. Functional flow diagram of leak detector

Integral correlator`s components are vibration sensors. They are devices that compose a wireless or wireline communication channel, as well as a computational module that can be implemented on various computational platforms. A general-purpose processor or a specialized digital signal processor [5] can be used as a basic platform. It should be noted that in some cases, a full-fledged portable PC is used as a calculation module. The latter case complicates the operation to some extent; hovewer, it significantly simplifies the task of software developing and makes cheaper the cost of the hardware part of the complex.

Based on the above-mentioned information, it should be noted that in general, the correlation leak detectors` software is a set of software solutions for various purposes. In particular, the implementation of the effective communication channel requires transmitted data packaging and monitoring of the received data integrity with the application of noiseless coding methods [8, 9]. At the same time, the organization of man-machine interaction involves results visualizing on the operator's display. This requires the use of special methods for displayed information preprocessing, taking into consideration the structure and data volume, as well as the need for functioning in a near-real time mode [10]. However, from the point of view of algorithmic and program realizations, the greatest interest corresponds to the problem of estimating the delay time by the correlation method [11].

3. Software implementation of data processing algorithm

Henceforth the implementation way of the leak detection complex is considered, assuming the use of a PC as the main computing device realizing signal processing [12]. In such implementation, there can be a presented portable microprocessor device for collecting, converting, storing and transmitting data to the PC in accordance with the functional diagram in Figure 1.

As previously stated, the digital signal processing is implemented programmatically and resolves into the consecutive application of spectral and correlation analysis methods [6]. Despite the fact that the mathematical apparatus for these operations was developed a long time ago and has been applied to solve the problem of detecting leaks [5], the issue of its further development still remains topical [3]. In particular, the cross-correlation calculating algorithm and the way of its realisation [11] have a significant effect on the efficiency of the computational resources use and, consequently, on the cost and speed of the hardware-software solution in principle.

The use of spectral analysis methods is conditioned by the correlation analysis limitations: a low signal-to-noise ratio typical for the problem under investigation affects the accuracy of leak detection negatively, and in some cases makes the result unreliable [12]. Some digital filters in combination with the methods of analyzing the signals spectrum are actively used to solve this problem. Among them are coherence function analysis, cross-phase spectrum analysis and some other methods [11].

In practise for the efficient application of digital signal processing methods their qualitative software implementation of analysis algorithms and, in particular, the fast Fourier transform (FFT) algorithm is required. Good implementation is based on the most complete use of available resources of PC computing elements – both the central processing unit and the graphics card. This requirement also extends to the realization of graphic components of spectral, time and spectral-time diagrams visualization and presentation of analysis results. The latter, in order to ensure the possibility of updating the image in real time, requires the use of modern technologies for graphical data mapping and specialized algorithms for their preprocessing [13].

Various approaches including algorithmic and architectural can be applied to improve the effectiveness of the vector data transformations implementation and other complex operations. However, the best result can be achieved by means of using a comprehensive solution which is based on the joint application of various approaches.

4. Prototype applying experience

A correlator prototype was created for the evaluation and applicability of the developed signal processing algorithms and corresponding software. The signal analysis software which is a prototype for the product, planned for exploitation, was developed within the Delphi 7 environment.

The functions, implemented in the prototype, were limited to reading signals (in the .wav format), their time and spectral diagrams visualizing (no interactivity was envisaged), using simple digital filters, correlation and time-frequency correlation processing, surface plotting of the time-frequency correlation function (interactive one, a separate module was implemented).

The comparison of the program with some Russian analogues revealed a number of significant faults, while the errors inherent at the development phase (the choice of a deprecated programming language, the monolithic application architecture, the neglect of the object-oriented approach principles) impeded their elimination. The following development areas were identified in the course of the analysis:

- «unhandy» and user-unfriendly interface;
- low speed while performing time-frequency correlation analysis;
- insufficient functionality of graphic components for data series visualization (especially 2D);
- absence of important signal processing tools which would improve the application efficiency of correlation processing in difficult conditions (weak acoustic signals, reflected waves presence);

- absence of any automation interpretation of the data at the correlator output (including the ability of an inner software evaluation of the signal propagation speed).

5. Development of the software solution concept

In connection with the abovementioned difficulties of the prototype improvement, it was decided to re-engineer the program for the analysis of signals in order to eliminate the drawbacks listed above.

On the assumption of a scope of the problem and the obvious lack of resources resulting from the small number of team participants working on the initiative project together with the main academic activities, it was decided to perform the further development in accordance with the cyclic iterative model [14]. The key factor of this decision was the absence of a steady feedback with an ultimate user which would have inclined the choice towards a spiral development model.

Taking into consideration the experience of prototype development and exploitation, and analyzing the documentation of some Russian analogical programs, the following final product basic requirements and the procedure of its development were formulated [14]:

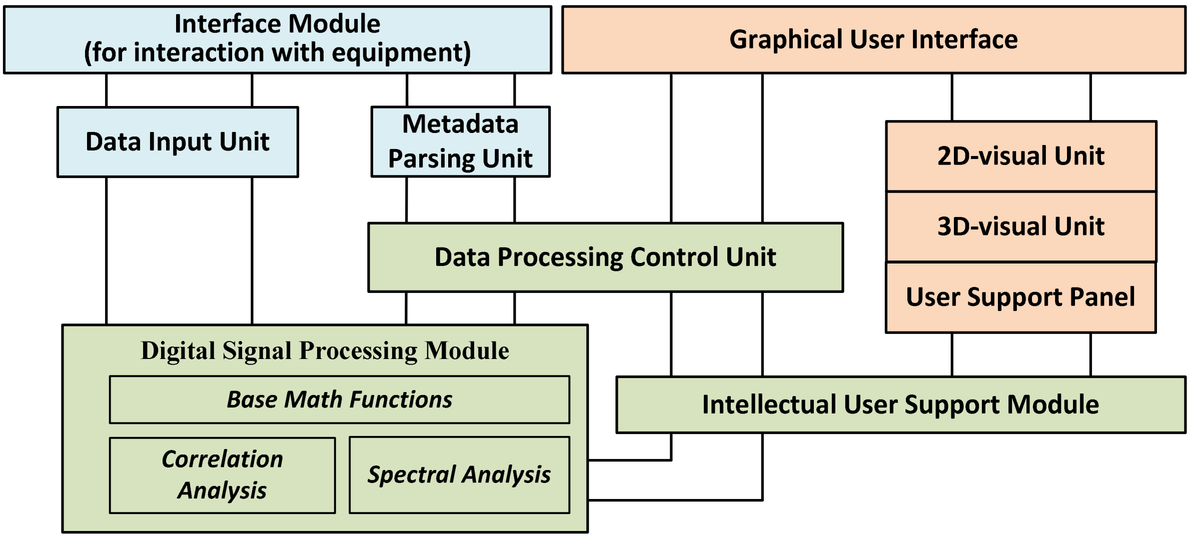

Figure 2. Software modular structure concept. Green colored modules are responsible for data processing and calculations. Blue colored modules are responsible for compatability with data formats used by equipment vendors. Orange colored modules are responsible for establishing user-friendly man-machine interface.

- Program architecture development and its structure at the development stage.
- Application of the object-oriented approach.
- Revision of the program mathematical core – development and optimization of a limited set of functions (fast Fourier transform, vector operations) for the further construction of signal processing methods based on them.
- Application of universal (having the possibility of flexible developer customization) and interactive visualization tools for a user.
- Optimization of demanding calculations realization by means of algorithms adaptation for parallel execution and their software implementation.
- Speed increasing of computing the time-frequency correlation function with the use of technologies of massive parallel data processing.
- Providing the possibility of flexible extension of analysis tools without introducing changes into the mathematical core, previously integrated analysis methods and user interface.

- User interface development with a limited application of the multi-document interface concept; use of an approach based on the analysis of the user's working practice while interacting with the system [15].
- Providing the ability to work with data formats used by other leak detector manufacturers.

In accordance with the formulated requirements, the concept of the software solution, presented in Figure 2, was developed.

6. Conclusion

In the present paper, the task analysis of the software correlator development that includes a PC was conducted. Potential difficulties connected with the need to ensure high speed while implementing time-frequency correlation estimation of the delay time and results visualization of the correlation analysis in the form of an interactive 3D surface are determined. Possible ways of solving the mentioned problems are considered.

With a foundation of the results of the task analysis, in accordance with modern principles of software engineering, the concept of the original software solution was developed. In future it is planned to develop a software product which is oriented towards application in combination with Russian-made correlation leak detectors on the basis of the given theoretical developments and the available backlog (developed analysis algorithms, parallel processing libraries, graphic components).

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