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PREPROCESSING OF EXPERIMENTAL DATA IN KORELIA SOFTWARE

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ABSTRACT
This work presents a system for primary processing and analysis of experimental data acquired from measuring devices. The main parameters of time series are defined. Data operations to extract parameters from the sequences, produce a similar sequence with particular enhanced or eliminated, encode or compress the sequence, etc are described. Manipulations of data are divided into three classes: manipulations of the independent variable, amplitude transformations and complex operations. Preprocessed time series are recorder in a few most popular file formats.

Key words: time-series analysis and manipulation, digital signal processing, computational statistics, time series management system,

INTRODUCTION

Integral part of modern measuring equipment and research is the possibility of data transmission to computer. The computer is a device that collects and preserves a data of the experiment. With the aid of the installed software such data are processed, analyzed and evaluated. For the broader community, the external devices, which are a tool of scientific research and that acquire the primary data will be called Data Circuit terminating Equipment (DCE). The computer and the software for accepting and processing the data will be referred to as Data Terminal Equipment (DTE). The transfer of data with the coordination of protocols for data exchange and the problems of compatibility of the DCE and DTE is discussed in [1].

After issues with transcode and transfer of data are resolved, there is a need for their treatment and evaluation in the process of obtaining them in the DTE. Signal processing requires preparation and time. In the course of the experiment is necessary to assess its appropriateness - whether to continue or begin a new experiment with modified initial conditions. In this manner is possible to avoid non-information measurements, to save time and faster to get the correct experiment. DTE is important because its possibilities define the effectiveness of research. Greater ease in the process of initial data evaluation is an opportunity of their immediate evaluation. It is the device in a data acquisition system which performs a significant amount of data reduction, extracting specific information from raw signal representations, in advance of the main processing operation.

The present work describes a system for data acquisition and primary signal processing based on software Korelia and called ‘Korelia-Processing’.

SYSTEM AND SIGNAL PROPERTIES

The experimental work and received in the process of its implementation data are irrevocably linked to notions of 'signal' and 'system'.

Signal

A signal can be defined as sequence of values by which data is conveyed regarding the state, characteristics, composition, and course of action or the intention of the signal source [2]. A signal is a means to transfer data. The data conveyed in a signal may be used by humans or machines for communication, forecasting, decision- making, control, exploration etc. The signal can be a function of one or more independent variables, but in most cases it depends on a time.

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System

A system is an object whose structure or behaviour is studied. It is the abstraction of a process or object that puts a number of signals into some relationship. The signal that represents the input influence upon the system **S** is called input signal **U(t)** and the signal, which express the system reaction over a time interval $\mathbf{t_p}$ – output signal $y_a(t)$. The character of $y_a(t)$ depends on system properties **S(t)** and input signal **U**(t) (**Figure 1).** For natural systems $y_a(t)$ is a continuous (analogue) set of real values $\check{R}$:

$$y_a(t) : \Re \rightarrow \Re \tag{1}$$

The system is a source of experimental data. Because these data are collected over time they are called 'time series'. The background of time series applications is very diverse.

Acquisition time

Depending on different applications, data may be collected hourly, daily, weekly, monthly and so on. The amount of time necessary to collect all of the data for a particular sequence defines the **a**cquisition time t_p. This time may be longer than is necessary for the experiment itself - an excessive amount of data after a certain time may not be sufficiently informative, but makes difficult data processing.

Settling time

After some time t_s (settling time) the observed signal enters and remains within a specified tolerance band ε related to the amplitude of expected final value Y_s.

$t_s : |y_a(t_i) - y_a(t_s)| < \varepsilon$ $\quad t_i > t_s$, $t_i \leq t_p$

Y_s: $|y_a(t_i) - Y_s| < \varepsilon$ $\quad \varepsilon$ is an tolerance (error) band

To facilitate the processing, a data received after time t_s can be removed. Settling time is of cardinal significance for data acquisition systems because it is the primary factor that defines the data rate for a given error level. The expected final value Y_s for convergence time series presents its accumulation point and will be called 'Steady state level'.

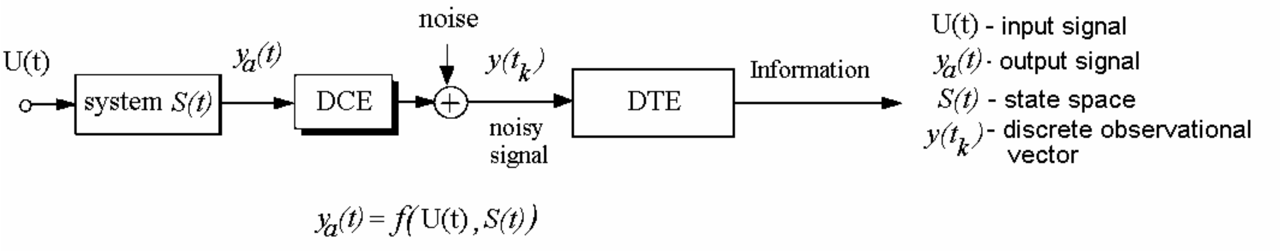

Figure 1. Signal flow

DCE realizes the process of data acquisition and transformation the signal representation from its original form into suitable representation for storage and subsequent processing, with or without modifications. Data acquisition is a process of registering and saving an experimental data. During the acquisition a finite set of values of the observed signal are recorded. Therefore the acquisition process can be accurately modelled as a sampling of the continuous set using a discrete partitioning. In this manner sampling converts an analogue signal into a discrete-time signal. A discrete-time signal is an indexed sequence of real numbers, i.e. it is a function of an integer-valued variable k, which is denoted by $y(t_k)$. Thus, $y(t_0),\ldots,y(t_{N-1})$ is a time series obtained by observing the **DCE** at N successive times $t_0,t_1,\ldots,t_{N-1}$. Formally, this time series is regarded as a function

$$y: t_0,t_1,\ldots,t_{N-1} \rightarrow \check{R}$$

that assigns to each time t_k a real number. The set $T=\{ t_0,t_1,\ldots,t_{N-1}\}$ is called the domain of $y{:}T{=}Domain(y)$. Thus **y** is the observational vector, which is known by the acquisition and is normally recorded in a storage device for subsequent data processing from **DTE**.

Depending on the method of forming a sampling interval, there are two types of time series.

- Homogeneous time series with regularly spaced sampling times: $y_k \equiv y(t_k) = y_a(k.\ \Delta t)$, $\Delta t = t_k - t_{k-1} > 0$ is a sampling interval, $k=0,\ldots,N-1$
  y_k is the signal value at time instant k and discretization Δt. Data which are collected by the **DCE** are in this category. Usually the discretization Δt is adjusted in accordance with the requirements of the specific experiment.
- Inhomogeneous time series meaning that the sampling times t_k are irregular. Such

time series are obtained if the research process is characterized by large dynamic changes and the time sampling of the **DCE** is configured to be inversely proportional to the speed of the process.

It is unavoidable that sampling leads to information losses. Therefore, it is important to select the sampling interval Δt so that these losses are insignificant for the given application.

STATISTICAL PARAMETERS OF SIGNAL

The length N of time series obtained at the output of **DCE** is a hundreds and thousands elements. This is a prerequisite for the calculation of some of their statistical characteristics. The listed below parameters are calculated for each interactive signal processing manipulation and thus can detect any deformation of the series and it be evaluated quantitatively.

- Minimum signal amplitude. This is the minimum value of the measured signal ***y***.

$Y_{min} = min(y_k), k=0,1,\dots,N-1$

- Maximum signal amplitude. This is the maximum value of the measured signal ***y***.

$Y_{max} = max(y_k), k=0,1,\dots,N-1$

- Range R_y of the signal. Denotes the variability of the time series.

$R_y = Y_{max} - Y_{min}$

- Average value of time series Y_{av}

$$Y_{av} = \frac{\sum_{k=0}^{N-1} y_k}{N} \qquad (2)$$

- Standard deviation **SD**. It makes sense for Gaussian distribution of time series. It is measure of the variability of amplitudes.

$$SD = \sqrt{\frac{\sum_{k=0}^{N-1}(y_k - Y_{av})^2}{N-1}} \qquad (3)$$

- Coefficient of variation **CV**. Shows the relative dispersion of the data expressed in percentages. This allows comparison of data with different ranges and distributions.

$CV = SD/Y_{av} * 100$ [%]

- Skewness **SK**. Skewness is a measure of the asymmetry of the probability distribution. For a sample of N values the sample skewness is

$$SK = \frac{\frac{1}{N}\sum_{k=0}^{N-1}(y_k - Y_{av})^3}{SD^3} \qquad (4)$$

- Kurtosis **K** is a measure of the peakedness or flatness of the probability distribution of experimental data:

$$K = \frac{\frac{1}{N}\sum_{k=0}^{N-1}(y_k - Y_{av})^4}{SD^4} - 3 \qquad (5)$$

- **AUC** – area under curve. Signal is a function of varying amplitude through time; it seems to reason that a good measurement of the strength of a signal would be the area under the curve. The **AUC** is interpreted as the total systemic exposure and is used as a criterion for evaluation of drug absorption, drug bioavailability, and drug concentrations over time. AUC is calculated using trapezoidal rule:

$$AUC = \sum_{k=0}^{N-2} \frac{y_{k+1} - y_k}{2}(t_{k+1} - t_k) \qquad (6)$$

- Signal energy E_Y. The area under curve may have a negative part. This negative part does not have less strength than a positive signal of the same size. This suggests squaring the signal. It turns out that what the energy of a signal E_Y is the area under the squared signal:

$$E_Y = \sum_{k=0}^{N-1} y_k^2 \qquad (7)$$

- Signal power P_Y. Power is a time average of energy (energy per unit time). This is useful when the energy of the signal goes to infinity.

$$P_Y = \frac{\sum_{k=0}^{N-1} y_k^2}{t_{N-1} - t_0} \qquad (8)$$

AUC, signal energy and signal power are values that can compare different time series and show how time series are changed in successive manipulations.

OPERATIONS ON TIME SERIES

Operations are applied to time series in order to effect some results, as extract parameters from the sequences, produce a similar sequence with particular enhanced or eliminated, restore the sequence to some earlier state, encode or compress the sequence, etc. Every operation produces a new time series from an existing time series. These manipulations may be classified either as those that are transformations of the independent variable t_k or those that are transformations of the amplitude of $y(t_k)$ (i.e., the dependent variable). Hereinafter will be briefly addressed these two classes of transformations and a list of those most commonly found in applications.

Operations of the independent variable

Sequences are often altered and manipulated by modifying the index k as follows:

$$y_k^{new} = y(f(k)) \qquad (9)$$

here $f(k)$ is some function of k. The most common manipulations include truncation, shifting, scaling, resampling, segmentation and etc. which are defined below.

- Truncation. The value of a truncated signal after the truncation time T is zero, i.e.

$$y^{new}_k = \begin{cases} y_k, \; 0 \leq t_k \leq T, \quad k = 0,1,2\ldots \\ 0, \; t_k > T \end{cases}$$

It is applied in case that an acquisition time t_p is very long and signals after a certain level of amplitude are not informative. That is the operation which is used to obtain the settling time t_s.

- Time shifting. If a system is time-invariant, system parameters are constant, i.e. they do not depend on time. In such system, the time shifting $f(k)=(t_k+\Delta t)$ of $y(t_k)$ with Δt is defined as

$$y^{new}(t_k)=y(t_k + \Delta t)$$

Time shifting is applied when there are differences in the coordinate system of signals in different experiments. This operation is most often used to set the first value of time series in the origin of coordinate system. Time shifting does not change the statistical parameters of the signal.

- Time scaling (dilation). This transformation is defined by $f(k)=A*t_k$. Dilation enlarges or shrinks signal features according to whether $|A| < 1$ or $|A| > 1$, respectively.
- Resampling. Resampling is a technique for creation a new version of the time series and digital images with a different dimension. Increasing the size of a treated set is called upsampling; reducing its size is called down sampling. If N^{new} is a number of elements in a new data set, the simplest resampling algorithm is:

$f(k)=\alpha.k$, where $\alpha = N/N^{new}$ is a resample interval

Due to the large number of data received from DCE, it is frequently applied operation aimed at reducing the number of experimental data. If the implementation of this operation dramatically changes the statistical parameters of the series, this is an indication of a serious distortion of the time series and the operation should be repealed. More precise resample algorithms are discussed in [3]. They are not applied in Korelia-Processing, since data preprocessing does not require much precision processing.

- Removing a subset. If more than three consecutive points are with equal amplitudes, internal points are removed. Such series can be obtained in an inappropriate choice of a very small interval sampling. In implementing this operation is obtained inhomogeneous time series.
- Segmentation. Segmentation is the process of breaking down a signal y into disjoint regions $T = \{T_1, T_2, ...\}$ of $Domain(y)$ into sub-regions and a logical predicate L, which determines the partitioning [4]. Predicate, who separates a time series in two subsets, first including elements from 0-th to (M-1)-th, and second - for the rest values looks like:

$$L: \begin{cases} T_1 = \{t_0, t_1, \ldots, t_{M-1}\} \\ T_2 = \{t_M, t_{M+1}, \ldots, t_{N-1}\} \end{cases}$$

Segmentation is applied when the set of data is extremely large and the processing and analysis of the results would be easier if the segments are considered separately.

Transformations of the dependent variable (Amplitude transformations)

This class of manipulations changes the dependent variable y and reflects on signal amplitude.

- Translation along the ordinate axis. Due to the nature of *DCE* measured amplitudes often are relative, not absolute values. Each point is translated with constant amplitude Δy:

$$y_k^{new} = y_k + \Delta y \qquad (10)$$

- Addition and subtraction of signals. The addition or subtraction operator transforms two series y_1 and y_2 that are defined over the same domain T into new time series y_Σ respectively:

$$y_\Sigma(t_k) = \begin{cases} y_1(t_k) + y_2(t_k), \quad k = 0,1,\ldots,N-1 \\ y_1(t_k) - y_2(t_k) \end{cases} \qquad (11)$$

and is formed by the pointwise addition/subtraction of the signal values.

Subtraction of signals is useful because it allows the separation of two signals of different nature. For example, after filtering a noise from the signal, if from the basic signal y_1, a filtered one y_2 is subtracted, then a noise component y_Σ will be received.

- **Amplitude scaling.** Amplitude scaling of a signal y_k by a constant C is accomplished by multiplying every signal value by C:

$$y_k^{new} = C.y_k \tag{12}$$

The scaling operation inverts the input signal when **C< 0**, amplifies the signal when $|C| > 1$, and attenuates the signal when $|C| < 1$.

- Interpolation. Interpolation is the estimation of the unknown, or the lost samples of a time series using a number of known samples at the neighbourhood points. A common application of interpolation is the reconstruction of a continuous-time signals $y_a(t)$ from a discrete-time signal $y(t_k)$. In Korelia-Processing interpolation is not realized. Spline and linear interpolation are instruments in Korelia-Dynamics [5,6].

Complex operations

These manipulations are usually compositions of operations on independent and dependent elements of time series simultaneously.

- Translation**.** Simultaneous implementation of time shifting and translation along the ordinate axis leads to two-dimensional translation of time series. If $\Delta t = -t_0$ and $\Delta y = -y_0$, then time series can be placed to start at coordinate origin.
- Transformation**.** In practice the experimental values lie within different ranges. Thus, features with large values may have a larger influence in the model function than features with small values, although this does not necessarily reflect their respective significance in the design of the classifier. The problem is overcomed by transforming the data so that their values lie within similar ranges. Thus transformation leads to reducing variety within the class of functions.

Let $C = [t_0, t_{N-1}] \times [Y_{\min}, Y_{\max}]$ is a time series area, and $C^{new} = [t_{\min}^{new}, t_{\max}^{new}] \times [Y_{\min}^{new}, Y_{\max}^{new}]$ is a new area. Then, the transformation is described by equations:

$$\begin{cases} t_k^{new} = t_{\min}^{new} + \dfrac{t_{\max}^{new} - t_{\min}^{new}}{t_{N-1} - t_0}(t_k - t_0) \\ y_k^{new} = Y_{\min}^{new} + \dfrac{Y_{\max}^{new} - Y_{\min}^{new}}{Y_{\max} - Y_{\min}}\left[y_k - Y_{\min}\right] \\ k = 0,1,2,\ldots,N-1 \end{cases} \tag{13}$$

- Normalization**.** The data vector $\mathbf{y_k}$ is transformed into an area $\mathbf{C_{norm}}$=[0,1]x[0,1]. This is partial case, when $t_{\min}^{new} = 0; t_{\max}^{new} = 1; Y_{\min}^{new} = 0; Y_{\max}^{new} = 1$ and the normalization is expressed with:

$$\begin{cases} t_k^{norm} = \dfrac{t_k - t_0}{t_{\max} - t_0} \\ y_k^{norm} = \dfrac{y_k - Y_{\min}}{Y_{\max} - Y_{\min}} \\ k = 0,1,2,\ldots,N-1 \end{cases} \tag{14}$$

Normalization is used in recognition algorithms for system identification [7].

- Filtering**.** Filtering is the most commonly used signal processing technique. Filters are usually applied to remove or attenuate an undesired portion of signal while enhansing the desired portion of the signal. One of the most basic theorems of filter theory is the Wold's decomposition theorem. It implies that any stationary discrete time stochastic_process can be decomposed into a pair of uncorrelated processes, one deterministic, and the other being a moving average process.

$\mathbf{y(t_k) = \psi(t_k) + \varepsilon(t_k)}$

where: $\psi(t_k)$ and $\varepsilon(t_k)$ are not correlated.
$\psi(t_k)$ is deterministic
$\varepsilon(t_k)$ is an uncorrelated error with zero mean.

The noise component $\varepsilon(t_k)$ leads to distortion of the useful signal, which may render it unusable. It is therefore necessary to make a filtration of the signal, thus the influence of the noise component can be greatly reduced [8]. Two approaches for filtering are realized.

- Linear smoothing filter. It introduces the moving average system given by [9]:

$$\psi(t_k) = \frac{1}{2m-1}\sum_{\kappa=-m}^{m} y(t_k) \tag{15}$$

- Least-squares noise removal filter. This algorithm minimizes the sum of the squares of the noise:

$$\psi(t_k) = \sqrt{\frac{\sum_{\kappa=-m}^{m} y^2(t_k)}{2m-1}} \tag{16}$$

Filtration averages the input signal values within a domain of length 2m+1 around each $y(t_k)$. Its effect on an oscillatory signal region is to blur the high and low signal values together. It also reduces background noise when the signal of interest is of relatively low magnitude.

- Differentiation**.** The most common approach to computing derivatives is finite differencing. At its simplest, the first derivative in point ***k*** is:

$$y_k^{new} = \frac{y_{k+1} - y_k}{t_{k+1} - t_k} \quad (17)$$

The program allows the calculation and graphical vizualization of the first and second derivative at time. In data analyzing the graphic expression of the velocity indicates the direction of the process intensity. Second derivative shows the direction and action intensity of main factors, which exerts an influence on the system. When the positive factors are predominant, the acceleration is positive too and contrary, a negative acceleration is an indication for negative feedback in the system [10, 11]. First and second derivative are calculated and displayed together to assess the quality of the observed process.

It is possible to apply a consistently repeated differentiations, but there exists a danger of instability of the operation (division by zero, arithmetic overflow), because the elementary algorithm is applied. N-fold differentiation of data is possible with a program Korelia-Dynamics, where spline-interpolation with subsequent differentiation is applied, which makes the process stable [6].

- Integration**.** The most commonly used input influence in experiment is Dirac delta function. To obtain the response of the system if the input signal is a step function, it is necessary to integrate the output signal. Numerical integration is done using trapezoidal rule and a new time series y^{new} is generated:

$$y_k^{new} = y_{k-1}^{new} + \frac{y_{k+1} - y_k}{2}(t_{k+1} - t_k) \quad (18)$$

- Envelope of time series. Envelope algorithm searches identical local extremes (only minimum or only maximum) and forms a new time series, which is accordingly upper or lower envelope of the source data.
- Data import/export between various file formats**.** This is an opportunity for processing data received from different ***DCE*** and recording the processed time series in various file formats. The following file formats are supported:
  - o XML. eXtensible Markup Language is a language developed by the World Wide Web Consortium (W3C). It is an industry-standard of representing hierarchical data structures, independent of hardware, software and application [12].
  - o Paradox data structures. Paradox is a relational database management system developed and wide gained from Borland Software Corporation.
  - o Comma Separated Value (CSV). CSV is one implementation of a delimited text file, which uses a comma (< , >) or semicolon (< ; >) to separate values. In this format are received a data from an Isolated Tissue Bath System TSZ-04/1 [13] and MS Excell.
  - o EPR Data format. Data generated from electron paramagnetic resonance (EPR) spectrometer systems EMX^{micro}, Bruker, Germany.
  - o SSP. Unique data format used in the system Korelia–Dynamics for studying of dynamics processes and mathematical modeling [6]. This is the recommended file format for recording data in order to allow the next data processing using programs from Korelia family.

GRAPHICAL VIZUALIZATION

To realize a graphical utilities a descendant of graphical class TChart and TDBChart [14] according to requirements in [15, 16] are created.

After each operation it is possible to see the graphics of the newly received data in a separate window and to assess whether the operation is appropriate. Permanent graphic display of data is not done. Due to the large data size the program performance will drop and will work harder. It is possible to examine the impact of several operations on the same data to compare results or those operations be applied consistently on the result already obtained.

The next kinds of data are visualized:

- Main time series.
- Time series after operation.
- Main time series together with first and second derivative.
- Histogram of the probability density functions of time series.

On graphics can apply some operations, such as:

Visualization

- Scatter data visualization.
- Linear-segment data visualization.

SET-operations

- Changing the screen coordinates.
- Changing the world coordinates.
- Set a graphics color.

GET-operations

- Coordinates of the nearest point indicated by the locator.
- Copy an image in MS Clipboard.

Output operations

- Save an image as 'BMP ' file.
- Print an image on printer.

EXAMPLE

On **Figure 2** is the main window of Korelia-Processing. Contractions of smooth muscle strips of rat's urinary bladder after treatment with hormone Angiotensin II are recorded [17]. Graphical visualization includes the force of muscle contraction together with first and second derivative.

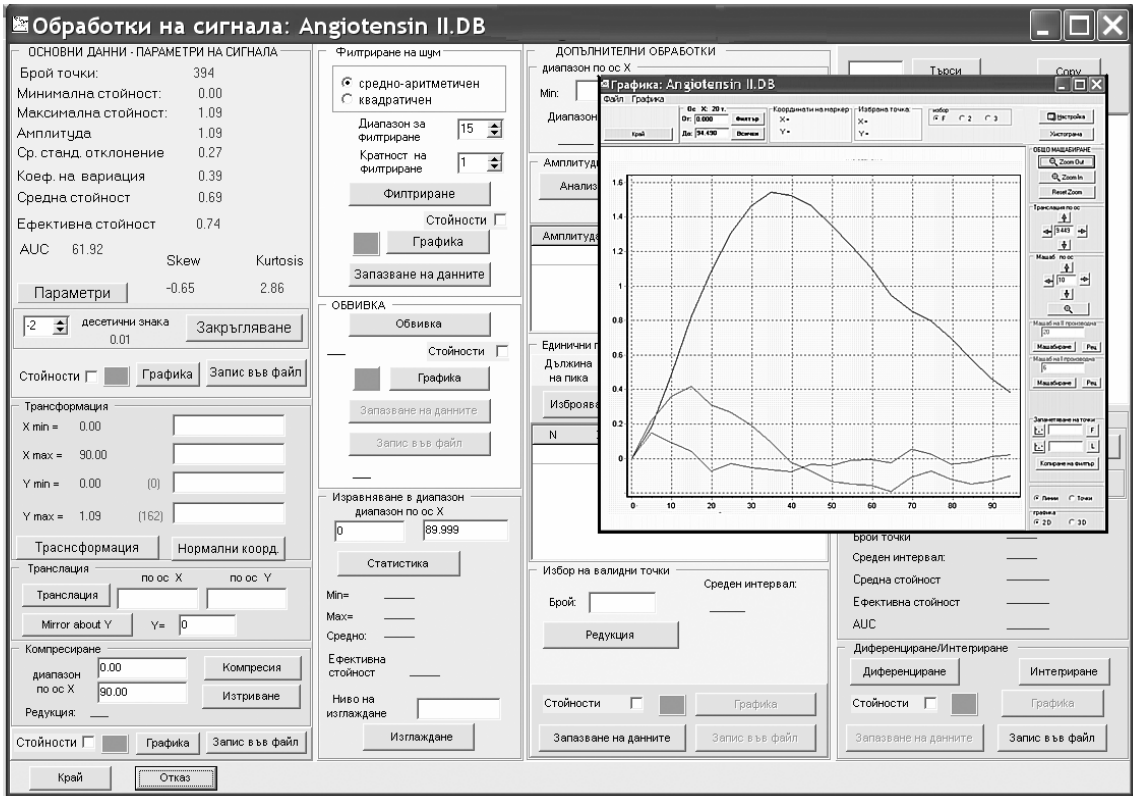

Figure 2. Desktop of Korelia-Processing. Angiotensin II treatment preprocessing

CONCLUSIONS

The modern devices used in scientific investigations have opportunities of data transmission to computers. Such data transfer leads to high degree of automation of the experiment and autonomy of the experimental procedure from being directly overseen by the scientist in each stage. The experimental data could be processed and evaluated with different applied software which contributes to the freedom and adaptability of the investigation.

Korelia is an interactive object-oriented Delphi application designed for the specific needs of time series analysis and identification. In the consistency of usage "Korelia-Processing" is the first. This work describes a capacity of Korelia-Processing at the initial stage of research-acquisition and preprocessing of experimental data:

- Basic terms are introduced specific for system and signal processing.
- Statistical calculations of time series are realized. They serve as control in data manipulations.
- Operations on time series are implemented and they are realized applying efficient algorithms.
- Customized graphical user interface is implemented. This is achieved by creation of graphical descendants of TChart and TDBChart for visualization and manipulation of graphics.
- File transfer from acquisition device to a computer and data exchange between popular file formats is implemented.

The structured object oriented design allows fast development, extensions and improvements of family Korelia to be implemented at any time.

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