VIRTUAL INSTRUMENTATION IN MEDICAL INVESTIGATIONS AND DIAGNOSIS SUPPORT

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Abstract-**The improvement in medical care, which we have observed in the last few decades, has been influenced by the introduction of new technologies and methods for monitoring the patient. Medical researchers working have been faced with large amount of different types of data (alphanumeric, signals, images), that are sometimes difficult to analyze using traditional methods. In order to extract maximum information from the collected data, introduction of sophisticated mathematical methods to medical sciences has been necessary.**

The aim of this article is to explain how virtual instrumentation concept may facilitate creation of tools, which may be useful both in medical investigations and diagnosis support. As the example we present the analysis of the fetal heart rate signal in time, frequency and joined time-frequency domain. The possibility of classification of such obtained results with statistical and artificial intelligence methods will be described.

Keywords **- virtual instrumentation, fetal heart rate, joined time-frequency analysis**

I. INTRODUCTION

One of the three basic types of medical data that must be acquired, processed and archived are biomedical signals. Diagnosis support based on signal processing consists of three main steps. The first one is a gathering the signal with the use of different sensors and its appropriate pre-processing (linearization, amplification, filtering). The second step is the analysis of such acquired data in time, frequency or joined time-frequency domain. There are a lot of mathematical techniques that allow the scientist to extract the optimal set of signal features describing an interesting object in effective way. The last step is classification of clinical status of examined patients based on previously defined and extracted features. Most frequently, these three steps are performed subsequently by means of separate software tools. The acquired data are transferred with export/import procedures of particular program to the another one, which executes next step of analysis. The described procedure is cumbersome, time consuming and may be potential source of errors.

In 1987 LabVIEW (National Instruments) was introduced – the language based on the concept of graphical programming [1]. Contrary to conventional textual languages it allows to concentrate only on the problem and omit all syntactical rules. Programs developed in LabVIEW are called as virtual instruments (VI) and are portable among different computer platforms as PCs, Macintoshes, Sun SPARC stations, Concurrent PowerMAX stations and HP PA/RISK workstations. This flexibility ensures that the programs prepared for one particular platform would be also appropriate to another one. One can exploit all of the power and processing capabilities of his computer without spending hours on learning how to use a program. Intuitive interface, advanced analysis capabilities and simple connection to external hardware facilitate creation of medical monitoring systems. LabVIEW is integrated fully for communication with hardware such as GPIB, VXI, PXI, RS-232, RS-485, and plug-in data acquisition boards. LabVIEW also has built-in libraries for using software standards such as TCP/IP Networking and ActiveX.

All described features simplify creation of software covering complex and sophisticated methods of signal acquisition and further processing [2, 3]. In subsequent chapters we present virtual instrumentation designed for acquisition of fetal heart rate (FHR) and its analysis in time, frequency and joined time-frequency domains.

II. MATHEMATICAL METHODS USED IN HEART RATE ANALYSIS

A signal which is probably the most interesting for the physicians is the heart rate signal [4]. The basic information about fetal well-being is just carried by fetal heart rate variability. This is the cause of great interest of many obstetricians and biomedical engineers to improve the algorithms of FHR analysis.

The obstetricians employ most frequently classical analysis in time domain. The baseline level, oscillation bandwidth, occurrence of decelerations and accelerations are the parameters commonly used in clinical practice [5, 6]. A more intensive analysis incorporates the descriptors of long- and short-term variability of fetal heart rate. A wide scope of indices such as Yeh, de Haan, Heilbron, Jongsma indices are based on arithmetic mean value, standard deviation and interquartile range [7-9]. Common use of descriptive statistical methods for FHR evaluation has enormous disadvantage of destroying the existing natural time sequence of the individual R-R intervals. This sequence contains important information about the hidden periodicity of occurring phenomena.

The model of heart rate variability described by Sayers [10] caused the interest of many researchers in analysis of FHR signal in frequency domain. Sayers stated that three major physiologically originating factors have the influence on spontaneous heart rate variability. These factors are:

- blood pressure dynamic control system,
- body temperature dynamic control system,
- respiration movement.

The variability mechanisms are mediated by the autonomic nervous system. The first spectral component is located around 0.1 Hz and seems to be a marker of the interaction between the sympathetic and parasympathetic systems. Since

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1973 hundreds of articles dedicated to this problem were issued. Many physiological experiments proved that increased sympathetic control activity on the heart like standing-up, tilt, Valsalva's maneuvre were followed by an increase of power in the range 0.05 - 0.15 Hz (called LF low-frequency peak) of HR spectrum. The similar results were observed in pathologies with predominant sympathetic tone.

The second factor that has influence on the heart rate variability is connected with thermoregulation and peripheral vasomotor control (renin - angiotensin system). Numerous experiments of the thermal stimulus influence on the heart activity were done (i.e., local cooling of limb) and the changes of peak amplitude in very low-frequency (VLF) range 0.01-0.10 Hz were confirmed. The distinction between VLF and LF areas is not sharp and these regions are partially overlapped.

The third factor affecting heart rate variability is connected with respiration rate and sometimes is called "respiratory arrhythmia". This phenomenon is controlled by the parasympathetic system and therefore the change in high-frequency (HF) region may be treated as a quantitative measure of the vagal control of the heart. The range of frequencies is different for adults (0.20 - 0.40 Hz) as well as for neonates and fetuses (0.60 - 1.00 Hz). The results reported in the last few years confirm the importance of heart rate signal examination in that domain, and its usefulness both in theoretical research and practical diagnosis.

The estimation of power spectral density is usually based on nonparametric procedures employing the Fast Fourier Transform [11]. A large class of discretely sampled deterministic and stochastic processes can be analysed using this computationally efficient approach. However one should bear in mind that FFT techniques have the following disadvantages:

- Frequency resolution is limited by the available data record duration, independently of the characteristic of the data or its signal to noise ratio.
- Windowing process, which is necessary to obtain finite data sequence from infinite length sample sequence, introduces so-called sidelobe leakage effect. This effect causes the distortion of the spectrum, especially suppression of weak signal main-lobe responses by strong signal sidelobes.
- There exists the necessity of averaging PSD in time or frequency domain (or both) to obtain statistically consistent spectra estimators.
- Poor data number reduction for further classification procedures.

The only way of frequency resolution improvement is the increase of recording time. However this method is not always possible. Let us consider the situation in which we want to estimate PSD in particular behavioural states of fetus or newborn [12]. The frequency range which covers most important biological events visible in FHR or NHR such as thermoregulation effect, respiration movements, baroreceptor regulation etc. spans from 0 to 1 Hz. If we want to obtain the frequency resolution 0.01 Hz we have to record 100 seconds time interval of the signal, i.e. over 1.5 minute, and if we want to improve the resolution to 0.005 Hz the analogous recording time will be equal to 200 seconds, i.e. over 3 minutes. The better resolution we want to obtain, the longer time intervals must be recorded. Sometimes the increase of time recording is not possible because:

- particular behavioural state may be shorter than demanded time recording,
- some nonstationarities such as accelerations or decelerations could appear during signal acquisition; periodogram procedures can be employed only for the analysis of stationary processes.

All the mentioned disadvantages of nonparametric methods based on Fourier transformation may be avoided with the use of parametric methods such as modified covariance or Burg algorithms [13]. The techniques of spectrum estimation based on autoregressive modelling guarantee superb frequency resolution (even with very short data stretches) and very good data reduction. This last feature is extremely important in diagnosis support, because it ensures optimal set of parameters that is not dependent on the length of the signal. The main problem in use of autoregressive methods of spectrum analysis is the proper choice of the model order. Too low model order gives not adequate frequency resolution and does not allow detecting the real spectral structure of the signal. Overestimated model order decreases the stability of estimators (increases variance) which results in occurring of artificial (spurious) peaks. The second problem is resulting from the fact that parametric methods of spectrum estimation are more sensitive to low values of signal to noise ratio than nonparametric techniques based on Fourier transformation.

The analysis of heart rate signal in frequency domain allows us to state whether some periodical components were present during the examination or not. We have no idea how long these components lasted, did they occur simultaneously or subsequently? On the other hand, both parametric and nonparametric techniques of spectral estimation assume stationarity of the signal analysed. In practice each pattern such as acceleration or deceleration as well as the change of the oscillation bandwidth are nonstationarities. The appropriate technique to deal with multicomponent and nonstationary signal is the analysis in joined time-frequency (JTF) domain [14, 15]. Another important property of this analysis is the ability to reduce a noise. This property is based on the fact that signal's representation in JTF domain concentrates in relatively small region, whereas random noise evenly distributes over the entire time and frequency band. The main problem of joined time-frequency analysis is the suppression of crossterms generated by components localized closely one to another along time or frequency axis. These crossterms resemble spurious peaks occurring in parametric spectral estimation and do not have physiological or pathophysiological backgrounds. This disadvantage joined with time-consuming calculations caused that JTF analysis is not a very popular technique of heart rate analysis among physicians [16].

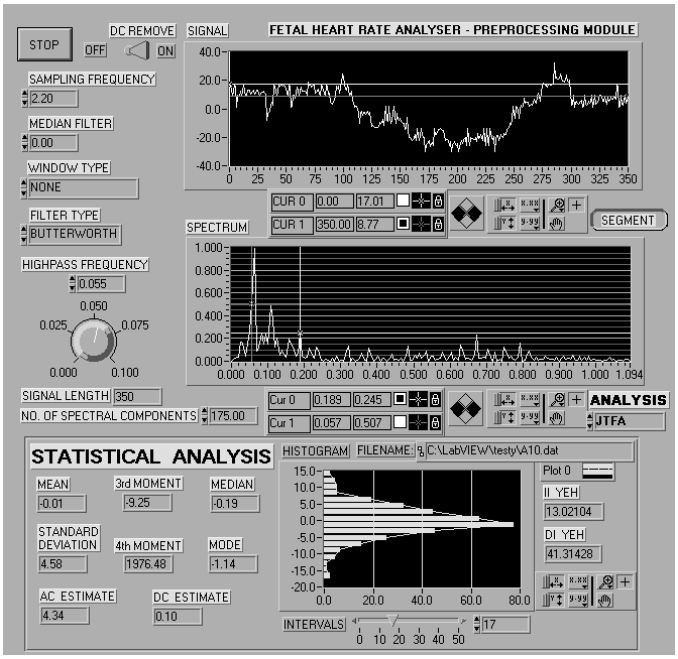

Fig. 1 Front panel of the virtual instrument designed for fetal heart rate analysis.

Each type of above mentioned analysis is the source of huge amount of data that should be correlated with clinical status of the patient examined. Most frequently, statistical methods based on hypothesis testing or correlation and regression are employed. However, when the appropriate number of cases is collected more sophisticated techniques such as discriminant analysis, fuzzy sets [17], rough sets or neural networks [18] may be used.

III. Virtual Instrumentation of Heart Rate Analyzer

All the biological signals carry information essential both for understanding the backgrounds of pathophysiological mechanisms and for making the proper diagnosis. Fetal heart rate signal represents the data concerned with fetal well-being. Each of described in previous chapter methods of signal analysis has different level of complexity and therefore is less or more time consuming.

Still unresolved problem is which fragments of FHR tracings should be used for fetal well-being prognosis – corresponding to different behavioural states. And how long should be the representative signal to infere reliable clinical conclusions. To achieve this goal Fetal Heart Rate analyser was designed using LABVIEW 5.1 package. The main assumptions are:

- FHR signal is obtained from fetal monitor digital output or sampled from its analog output with 2.2 Hz and subsequently stored in ASCII data files on computer hard disk.
- Signal length may vary from few seconds to many hours. Simultaneously to FHR recording, the behavioural status of the fetus may be observed with ultrasonography equipment.
- Crucial point of the analysis is to find interactively the proper signal subsegments. FHR Fourier spectrum is only an indicator and should be obtained as quick as possible. The exact comparative analysis would be done after subsegments defining with more time-consuming autoregressive methods or in joined time-frequency domain.
- Final graphical interface of the system should be as simple as possible. On the other hand, it should allow easy switching between modules described in previous section.

The concept of virtual instrumentation allows higher productivity in program creation, because many important high-level operations have been encapsulated in convenient virtual instruments libraries and may be quickly used. Fig. 1 presents front panel of the designed virtual instrument Fetal Heart Rate Analyser – Preprocessing Module. The switcher "Analysis" allows to find appropriate type of analysis from the set of methods described earlier.

IV. Conclusion

Modern digital signal processing methods give the researchers powerful tool for detailed analysis of medical data and their further maintenance. However, the complexity of algorithms in use makes the designing of such systems very difficult and cumbersome. The concept of virtual instrumentation considerably facilitates programming procedure. The virtual instruments designed are self-documented, flexible and may be easily adapted to the need of particular experiment.

Using LabVIEW Application Builder one can create executable programs. Prepared programs may be distributed and installed on other computers.

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