Novel Approach for Visualization of Patient Monitoring Parameters

Volodumir O. Fesechko, Yevgeniy Karplyuk
Department of Physical and Biomedical Electronics of National Technical University of Ukraine “Kyiv Polytechnic Institute”
Kyiv, Ukraine
yevgeniy@karplyuk.kiev.ua

Valeriy L. Tkachenko
UTAS Co.
Kyiv, Ukraine

Abstract — This paper proposes a novel approach for visualization system of patient monitoring parameters in real time, which integrates modern true-color graphics advantages of modern visualization devices, increasing signal processing abilities of modern functional monitoring modules and wireless network technologies. This approach enables continuous patient monitoring for diagnostic procedures on new level of usability and reliability of diagnostic parameters in actual time, regardless of monitoring events complexity.

Keywords — patient monitoring; monitor parameter; true-color graphical parameter representation; real time

I. INTRODUCTION

Advances in information technology, digital processing techniques as well as the increased computing power of hardware of patient monitoring allows to review approaches to the patient monitoring systems information in general, and monitoring parameters reliability in particular. The key point of all critical care transport is the continuous monitoring of vital signs, regardless of unfavorable environments for signals registration. Despite the development of new and continuous improvement of existing algorithms for computing signal analysis parameters [1-5], the accuracy of the numerical parameters monitored are often insufficient and inferior analytical expert conclusion [6-9]. In most cases, the algorithms provide accurate estimates but rarely results values can be unreliable, so-called slips. This situation reduces the level of confidence in monitoring means and inevitably increases the chance of missing a dangerous episode in monitoring the patient's condition.

The purpose of the relevant today monitoring system is expanding the capabilities of existing methods of monitoring and implementation of diagnostic procedures, regardless of the location of the patient in the current period. The main goal of modern monitoring systems is to enhance patient care by providing reliable, intuitive, clinically focused vital signs monitoring devices for use in a wide range of inpatient and outpatient environments, such as conscious sedation, respiratory therapy, sleep, emergency medical services, and transport.

Patient monitoring is vital to care in operating and emergency rooms, intensive care and critical care units. It can reduce the risk of infection and other complications, as well as assist in providing for patient comfort.

One way of providing additional diagnostic information is to increase informativity of parameters due to specificity of human perception, in particular to obtain information about rare but diagnostically important episodes at the same time as usual regular numeric parameters. The most promising is to use graphical colored representation, that gives additional parameter trend and statistic information in conjunction with time actuality.

This paper presents novel method of patient parameters visualization by monitoring system, which gives more information to experienced users to make right decision in quasi-real time. This is achieved by providing information not only in digital form, but intuitive full-color graphic image perceived, to enhance patient care.

II. MAIN CONCEPT OF NOVEL REAL TIME MONITORING PARAMETERS REPRESENTATION

In general, the main principles of proposed method of patient parameters visualization can be summarized as follows:

- The monitoring system must provide commonly accepted numeric parameters, which gives the reliable values in most patient conditions.
- The monitoring system must provide additional graphic representation of statistic of parameter values and its distribution in certain time window.
- The monitoring system must provide additional graphic representation of statistic of parameter trend in a compact form.
- The monitoring system must provide more mapping to represent more complex relationships in a one-dimensional parameter values series, something like a scatter plot.
- Using a modern graphic ability of visualization systems (true-color high-resolution TFT displays, graphic smoothing, etc.)

One of the basic concept of proposed real-time monitoring parameters representation is to use “Digital Phosphor”
techniques, which commonly used in modern digital oscilloscopes [10]. The name “Digital Phosphor” derives from the phosphor coating on the inside of cathode ray tubes (CRTs), which was used as displays in televisions, computer monitors and older test equipment. When the phosphor is excited by an electron beam, it fluoresces, lighting up the path drawn by the stream of electrons. LCD displays replaced CRTs in many applications due to their smaller depth and lower power requirements, among other advantages. However, the combination of phosphor coatings and vector drawing in CRTs provided several valuable benefits. Persistence and proportionality do not come naturally to instruments with LCDs and a digital signal path. But the analog benefits of a vector CRT could be achieved due to “Digital Phosphor” technology, that means CRTs phosphor emulation. Digital enhancements such as intensity grading, selectable color schemes and statistical traces communicate more information in less time.

Fig. 1 shows the monitoring parameter time series, with so-called time parameter trend and selected time window. For example, heart rate was selected as one of typical and most significant monitoring parameter. We used data from MIT-BIH Arrhythmia Database [11]. This example leads us immediately to a much more complex problem heart arrhythmias analysis with hiding some this complexity from the end user, but at the same time giving him maximum control and information.

Fig. 1. Monitoring Param Time Series with Time Window values Highlighted

Fig. 2 illustrates the commonly used information representation for heart rate (HR) monitoring.

Fig. 2. Patient Monitoring: commonly used HR window [12]

Commonly used HR information representation in digits, as showed for example, does not provide reliable information for this parameters when state of the patient changes dramatically. The situation is further complicated by the fact that the classical patient monitoring is necessary to use multiple monitoring parameters, and therefore part of the display screen to render a single parameter is quite limited.

The proposed method needs to select predefined sliding time window, which gives actual quasi-real time parameters data information and parameter statistics calculation ability.

III. REAL TIME TIME-COLORED MONITORING PARAM HISTOGRAM

Fig. 3 shows the possible way of monitoring parameter distribution representation with time actuality information due to third color axis. The classical histogram bars are colored by some function of actual time value sample according to selected color-map. This function was called time-actuality function and gives information about monitoring parameter values according to relative time.

Fig. 3. Proposed Monitoring Param Representation by Real Time Time-Colored Histogram

Color axis value gives quasi-real time information about current parameter value in terms of selected time series values distribution.

The simplest time-actuality function can be:

\[ ta(t) = t, \]

where \( t \) – sample time in some units.

Or in terms of digital signal:

\[ ta(i) = i, \]

where \( i \) – sample time in some (for example sample number).

The more complex time-actuality function:

\[ ta(t) = e^{-a(t+b)}, \]

where \( t \) – sample time in some units, \( \alpha \) – “forgetting factor” coefficient, \( \alpha \) – some time shift and normalizing coefficient.
Or in terms of digital signal:

\[ ta(i) = e^{-a_{(i-1)}} \]

where \( i \) – sample time index (for example sample number), \( a \) – “forgetting factor” coefficient, \( i_0 \) – time window end index.

\[ ct = \sum_{j=1}^{i_2} ta(t_j) \cdot (x_j \in X_j) \]

IV. REAL TIME TIME-COLORED SCATTER PLOT OF MONITORING PARAMETERS

The evaluation of the scatter plot, which described the relation between any given monitoring parameter value against the successive value, provides information about the complexity of the parameter variation, while a time order is ignored. If the consecutive parameter values had a similar duration, the scatterplot showed a ‘torpedo-like’ pattern and the complexity was considered to be low. In contrast, if the differences between consecutive values were large, then there was a widely dispersed pattern and high complexity was assumed [13-14]. But classic scatter plot loss time-actuality information. In this paper improving information and visibility is being possible due to color axis addition is proposed.

Fig. 4 shows the predefined monitoring parameter time window time-colored scatter plot. Each plot point (patch) are colored according to selected color-map by time-actuality function of parameter value.

Moving predefined time window makes this approach quasi-real time, so used can view animated representation of parameter variation and its trajectory in terms of phase space.

V. REAL TIME RECURENCE PLOTS OF MONITORING PARAMETERS

A recurrence plot (RP) is an advanced technique of nonlinear data analysis. It is a visualization (or a graph) of a square matrix, in which the matrix elements correspond to those times at which a state of a dynamical system recurs (columns and rows correspond then to a certain pair of times). Technically, the RP reveals all the times when the phase space trajectory of the dynamical system visits roughly the same area in the phase space [15, 16].

Eckmann et al. [15] have introduced a tool which can visualize the recurrence of states \( x \) in a phase space. Usually, a phase space does not have a dimension (two or three) which allows it to be pictured. Higher dimensional phase spaces can only be visualized by projection into the two or three dimensional sub-spaces. However, Eckmann’s tool enables us to investigate the m-dimensional phase space trajectory through a two-dimensional representation of its recurrences. Such recurrence of a state at time \( i \) at a different time \( j \) is marked within a two-dimensional squared matrix with ones and zeros dots (black and white dots in the plot), where both axes are time axes. This representation is called recurrence plot (RP). Such an RP can be mathematically expressed as

\[ R_{i,j} = \Theta(x_i - x_j) \]

where \( N \) is the number of considered states \( x_i \), \( \varepsilon_i \) is a threshold distance, \( \|x\| \) a norm of \( x \) and \( \Theta(z) \) the Heaviside function [16].

Fig. 5 shows the predefined monitoring parameter time window recurrence plot.
The initial purpose of RPs is the visual inspection of higher dimensional phase space trajectories. The view on RPs gives hints about the time evolution of these trajectories. The advantage of RPs is that they can also be applied to rather short and even nonstationary data.

The RPs exhibit characteristic large scale and small scale patterns. The first patterns were denoted in [16] as typology and the latter as texture. The typology offers a global impression which can be characterized as homogeneous, periodic, drift and disrupted.

Homogeneous RPs are typical of stationary and autonomous systems in which relaxation times are short in comparison with the time spanned by the RP. An example of such an RP is that of a random time series.

Oscillating systems have RPs with diagonal oriented, periodic recurrent structures (diagonal lines, checkerboard structures). For quasi-periodic systems, the distances between the diagonal lines are different. However, even for those oscillating systems whose oscillations are not easily recognizable, the RPs can be used in order to find their oscillations.

The drift is caused by systems with slowly varying parameters. Such slow (adiabatic) change brightens the RP’s upper-left and lower-right corners.

Abrupt changes in the dynamics as well as extreme events cause white areas or bands in the RP. RPs offer an easy possibility to find and to assess extreme and rare events by using the frequency of their recurrences.

VI. CONCLUSIONS

The novel method of patient parameters visualization by monitoring system is proposed and main concept of true-color real time monitoring parameters representation was illustrated. Proposed approach provides backward compatibility of classical numerical parameters representation. The real time colored monitoring parameter histogram gives statistic and its values distribution with emphasis to time actuality in selected time window. The real time scatter colored plot gives possible associations or relationships in monitoring parameter series with emphasis to time actuality in selected time window.

Quasi-real time recurrence plot is an advanced technique of nonlinear data analysis. Visual inspection reveals that typical system have a unique recurrence structure. In noise signal there is hardly to define any structure, periodical signal have long continuous lines on recurrence plot and chaotic signals recurrence plots are somewhere in between of noise and periodical signals. This visualization approach gives large amount of information about the behavior of the parameter in the compact form.

Using intuitive full-color graphic image for monitoring parameters visualization techniques, which provide information of statistics and time actuality, will improve the accuracy and reliability of monitoring in general and especially in non-trivial patient situations.

REFERENCES