ICM+: software for on-line analysis of bedside monitoring data after severe head trauma

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Summary

ICM software was developed in 1986 in Warsaw, Poland and has been in use at the University of Cambridge Neurocritical Care Unit for 10 years collecting data from bed-side monitors in nearly 600 severely head injured patients and calculating secondary indices describing cerebral autoregulation and pressure-volume compensation. The new software ICM+ includes a much extended calculation engine that allows easy configuration and on-line trending of complex parameters.

The program records raw signals, and calculates time trends of summary parameters. Configuration and analysis utilises arithmetic expressions of signal processing functions to calculate various statistical properties for each signal, frequency spectrums and derivatives, as well as correlations/cross-correlations between signals. The software allows configuration of several levels of analysis before calculating the final time trends. The final data are displayed in a variety of ways including simple time trends, as well as time window based histograms, cross histograms, correlations etc. All this allows complex information coming off the bed-side monitors to be summarized in a concise fashion and presented to medical and nursing staff in a simple way that alerts them to the development of various pathological processes.

The system provides a universal tool for clinical and academic purposes. Its flexibility and advanced signal processing is specialized for the needs of multidisciplinary brain monitoring.

Keywords: Brain monitoring; multimodal monitoring; on-line data analysis; cerebral autoregulation; head trauma; intensive care; neuro-monitoring.

Introduction

In an established environment of Clinical Neuroscience Department enormous quantities of data can be captured from bed-side monitors per each patient [5]. From that data information regarding cerebral autoregulation, cerebrospinal compensatory reserve, oxygenation, metabolite production and function can be obtained [1, 3, 6]. However, continuous assessment of changing cerebrovascular haemodynamics and oxygenation demands not only reliable monitoring techniques, but also sophisticated and time consuming signal analysis. This can be provided by dedicated computer support.

The intensive care multimodality monitoring system adopted in the Cambridge Neurosurgical Unit is based on software for a standard PC, equipped with a digital to analogue converter and RS232 serial interface, running Windows 2000/XP. First version of the software was introduced into clinical practice in Poland, Denmark and the UK in the middle 1980s and has subsequently been extended into a system for multimodal neuro-intensive care monitoring (ICM) and waveform analysis of intracranial pressure [1, 8] used in Cambridge, UK, and other centres in Europe (Goteborg, Toulouse) and United States (Detroit). Most data has been derived from head injured [3] and hydrocephalus patients [2]. However, the same or similar techniques are being increasingly applied to those suffering from severe stroke, subarachnoid haemorrhage, cerebral infections, encephalopathy, liver failure, benign intracranial hypertension, etc. In addition to monitoring of multiple variables describing dynamics of the studied pathology [5], some secondary indices have proved to be useful in clinical neurosciences [6]. The best known example is the cerebral perfusion pressure, calculated as a difference between mean arterial pressure and ICP. More sophisticated indices describing cerebrospinal compensatory reserve, pressure autoregulation and vascular reactivity were introduced to clinical practice recently and proved to be useful in head injury [3, 5] or poor grade subarachnoid haemorrhage. The aim of this paper was to present and discuss the concepts implemented in the new version of the monitoring soft-
ware ICM+ and to show its applications in research of Neurosurgical diseases and head traumas.

Methods

The ICM+ software extends the ideas included in the original ICM program for DOS [1] as well as in the cerebrovascular reactivity test analyzer CVRTest [8] by the same authors. In particular, the principle of multistage analysis of the bedside monitors signals has been carried through (Fig. 1). It has however been extended heavily based on the authors experience over the years of using the software in the neuro-intensive care unit in the Addenbrookes Hospital, Cambridge.

The software is composed of several modules of which the core are:

1. Sampler module – collects data from variety of sources including analogue/digital converter and RS232 serial port. Configuration of the analogue input involves specifying sampling frequency, actual analogue channel to be used for particular signal as well as the voltage amplifier gain and the voltage-signal units conversion. Configuration of the serial input involves communication protocol, specifying record and data field separators as well as the position of the particular data field in the data record. All the signals are provided to sampler clients as one list with their respective sampling rates, hiding the actual signals sources. There is also an off-line version of the sampler that uses a data file (several formats are supported) instead of directly reading the data from bedside monitors.

2. On-line Data Analysis module – collects signal samples from the Sampler and processes them according to requested analysis configuration (Fig. 2) producing time trends of calculated parameters. Rather than creating new file with each configuration change ICM+ often uses only during certain time periods rather than for the whole time of patient’s stay in the ICU. Those devices, e.g. TCD, Neurotrend, NIRS etc, are highly sophisticated multi-channel digital trend recorders with built-in options for complex signal processing [1, 8]. The considerable flexibility of such systems allows almost unlimited signal analysis, which can generate a state of data chaos. Thus the modern user is faced with the problem of which parameters should be considered, and how the data should be interpreted. The information should then be presented in a manner that is comprehensible to medical and nursing staff. Decision on which calculated parameters are clinically most relevant should be made by the clinical staff in collaboration with their research colleagues. Those carefully selected parameters, and only those, should then be presented continuously on the computer screen. Flexible configuration of data views implemented in ICM+ software allows for designing a clear summary view page for the clinically relevant parameters and additional, readily available pages containing all the other calculated parameters for more advanced clinical users or research fellows.

Results

The software has been used in a variety of applications covering various neurological pathologies ranging from hydrocephalus, stroke to severe head injury. For the last two years it has been used routinely in the neuro-intensive care unit in the Addenbrookes Hospital, Cambridge, UK. Total number of 78 patients has been monitored/diagnosed using this software. Case studies exemplifying the software application in different neurological condition are presented in Figure 3. More examples of research and clinical applications of the software can be found on the web site http://www.neurosurg.cam.ac.uk/icmplus.

Discussion

Data from various monitoring equipment used in an intensive care unit contains a wealth of information about the patient’s state. Some of the signals coming from the monitors are more complex than others, i.e. include complex waveforms. Instantaneous values of those signals are often difficult to interpret. Trends of minute by minute averages travel far to aide in interpretation of the monitoring data but they completely dispose of information carried by the waveforms. Also, it is often the strength and character of association between different signals that provides extra information rather than the signals themselves.

The first specialised computer-based systems for neuro-intensive care were introduced at the beginning of the 1970s. Initially these systems were oriented to the monitoring of ICP and ABP allowing calculation of CPP and a basic analysis of the pulse waveform. In contrast, contemporary systems, like the one presented here, are highly sophisticated multi-channel digital trend recorders with built-in options for complex signal processing [1, 8]. The considerable flexibility of such systems allows almost unlimited signal analysis, which can generate a state of data chaos. Thus the modern user is faced with the problem of which parameters should be considered, and how the data should be interpreted. The information should then be presented in a manner that is comprehensible to medical and nursing staff. Decision on which calculated parameters are clinically most relevant should be made by the clinical staff in collaboration with their research colleagues. Those carefully selected parameters, and only those, should then be presented continuously on the computer screen. Flexible configuration of data views implemented in ICM+ software allows for designing a clear summary view page for the clinically relevant parameters and additional, readily available pages containing all the other calculated parameters for more advanced clinical users or research fellows.

Multiple data sources

In a research orientated intensive care unit there may be several other monitors available in addition to the standard bedside monitors of ABP and ICP. Those devices, e.g. TCD, Neurotrend, NIRS etc, are often used only during certain time periods rather than for the whole time of patient’s stay in the ICU. Rather than creating new file with each configuration change ICM+ can accommodate those changes in its native file format and presents the whole patient data across different configuration as one time strip.