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Cardio 7 - Portable System for High Resolution ECG Mapping

V. ROSÍK, M. TYŠLER, Š. JURKO, R. RÁŠO, M. TURZOVÁ

Institute of Measurement Science Slovak Academy of Sciences, Dúbravská cesta 9, 842 19 Bratislava, Slovakia

Abstract. One of the main difficulties in using body surface potential mapping (BSPM) techniques is the need of complicated multi-channel measuring system. In this paper practical portable ECG mapping system is introduced. The system consists of a notebook computer and a data acquisition system box connected to the computer by fast IEEE 1284 parallel interface working in ECP mode. Concept of the device enables to extend the basic 134-channel high-resolution multi-channel ECG amplifying unit up to 256 channels. Application software includes measurement and real time monitoring of ECG signals, computation and display of several types of body surface potential maps. System can be connected to hospital information networks and supply them with measured ECG data for advanced processing or central archiving.

1. Introduction

Body surface potential mapping (BSPM) is a non-invasive electrocardiographic method enabling more precise diagnostics of cardiac diseases based on detailed registration of surface cardiac potentials using increased number of sensing electrodes. During the last 3 or 4 decades, experience with different lead sets for mapping showed that information contents in maps constructed from 24 to 32 leads is not substantially greater than that of standard 12-lead ECG. Nevertheless, model studies prove that maps constructed from about 100 or more leads could substantially improve the diagnostic value of the maps. Moreover, BSPM in connection with systems for assessment of precise torso geometry, such as MR and CT tomographs or ultrasound systems, can supply data for advanced diagnostic methods used e.g. for non-invasive localization of arrhythmogenic tissue.

Cardio 7 system described in this paper is designed for recording of ECG signals high resolution BSPM using several electrode sets including up to 6 limb leads and 128 unipolar chest leads. If necessary, it can be extended up to 256 measuring cannels.

2. Concept of the mapping system

Cardio 7 mapping system is designed as a specialized portable or mobile configuration of a multi-channel amplifying and measuring subsystem placed in patient terminal box and connected to a personal computer by fast parallel interface IEEE 1284 working in ECP mode. The patient terminal is powered by isolated power supply or battery block controlled by the computer and placed in separate shielded box. If desired, the computer can be also connected to standard hospital or university network.

In the mobile configuration, computer and patient terminal are placed on a special carriage easily transportable by 1 person. Its dimensions permit to pass through standard doors, passages and lifts and to use the system as a bedside unit. The patient terminal box is detachable from the carriage and its remote operation is possible. Block scheme of the Cardio 7 system is shown in Fig.1.

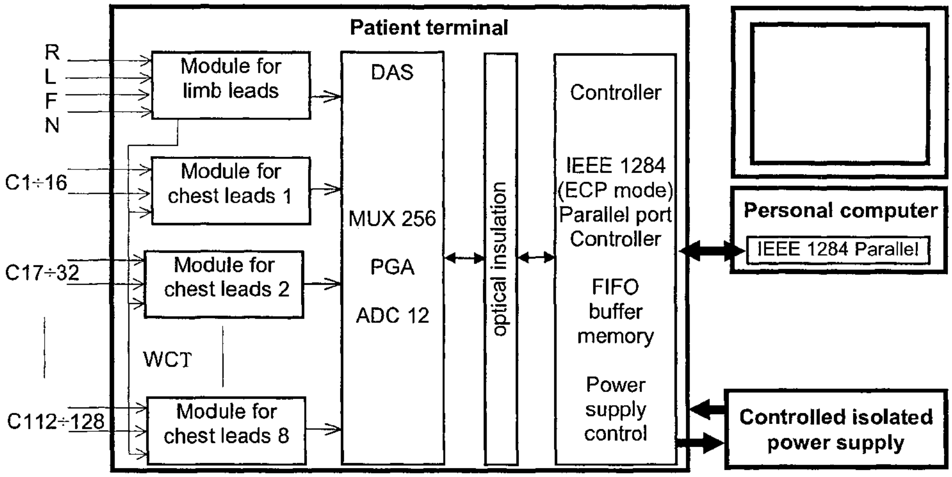

Fig. 1: Block scheme of the Cardio 7 mapping system in basic 134-channel configuration.

This concept of the device enables independent design and selection of basic parts of the mapping system and setting of optimal configuration corresponding to the user's requirements to number of channels, portability of the system, signal processing speed, and the system price. Structure of the patient terminal unit enables to build a measuring system respecting regulations for medical electrical equipment of type BF or CF and using almost any commercial personal or notebook computer.

From the user's point of view, the mapping system has following important features:

- standard PC or notebook with IEEE1284 fast parallel port is used; no hardware intervention into the PC unit is needed during system installation or service,
- optical isolation of the measured object enables measurement of surface ECG signals for BSPM as well as recording of patient's heart electrograms for direct cardiac mapping (with CF-type unit),
- contact of measuring electrodes is checked and faulty leads are reported on computer display during the test phase of the measurement process,
- programmable upper cut-off frequency and gain in each measuring channel enables optimal recording of ECG signals with different amplitudes at different sampling rates,
- standard bipolar and unipolar ECG leads are generated by the hardware of the measuring unit.

3. Patient terminal unit

Patient terminal represents a data acquisition system (DAS) for use in biology and biomedicine. It consists of three basic sections:

- modular amplifying section,

- measuring section containing optoelectronic insulation and 12-bit converter,
- interface section with micro controller, data buffer and fast parallel port driver.

The role of the amplifying section is to optimize amplitudes and frequency content of ECG signals from body surface or from epi- and endocardium for the DAS inputs. It fulfills safety requirements for ECG measuring equipment [1] and arrangement of measured leads conforms to demands for ECG lead standards [2]. Individual disposable adhesive pre-gelled Ag-AgCl electrodes are used for ECG recording because of their low cost and small differences of polarizing potential.

Signals from limb electrodes R, L, F are processed in one limb lead module LL6A, signals from chest electrodes C1, C2, ... are processed in up to eight 16-channel unipolar chest lead modules CL16A. Maximal configuration of the patient terminal contains 6 measuring channels for standard limb leads and 128 channels for unipolar chest leads.

Neutral electrode N on the patient's left leg is connected to the output of a neutralization amplifier. It supplies to the patient an amplified and inverted signal of the common mode voltage derived from the R electrode. Level of disturbing common mode voltage on the patient caused by the presence of 50 Hz noise in the environment is substantially reduced by this active neutralization. Common mode interference caused by currents induced into lead cables by capacitive coupling with power lines is minimized by shielding of the lead cables. To reduce the influence of the capacity of cable shielding on the stability of the neutralization loop, all shieldings are driven by a common mode voltage signal derived from the R electrode.

Signals from R, L and F electrodes are preamplified in the limb lead module and connected to the standard Wilson/Golberger resistor network. Signals from its nodes are processed in 6 differential amplifiers and Einthoven's bipolar limb leads I, II, III and Golberger's augmented limb leads aVR, aVL, aVF are available on their outputs. Potential of the Wilson's central terminal (WCT) obtained in the Wilson/Golberger resistor network is used as the reference potential for all unipolar leads and is fed to the inverting inputs of all differential amplifiers in the chest lead modules CL16A.

Signals from chest electrodes C1 to C128 and from WCT are led to the inputs of differential amplifiers in the chest lead modules CL16A and unipolar chest lead signals U1 to U128 are generated. ECG signals from outputs of differential amplifiers in LL6A and CL16A modules are fed into active band-pass filters where the upper cut-off frequency of all measuring channels can be set to 100, 250, 500 or 1000Hz under program control.

Each filtered ECG signal is led to input of one CMOS single-pole-double-throw (SPDT) switch. Output of corresponding ECG preamplifier is connected to the second SPDT input. During the lead test phase, all signals from preamplifiers are switched-over to channel outputs. In this way, contacts of measuring electrodes and integrity of measured leads are checked and faulty leads are on-line marked on the computer display.

Outputs of SPDT switches are finally connected to a 16-channel analog multiplexer that forms one output from each LL6A or CL16A module. Outputs of these multiplexers are fed to inputs of the measuring section.

Measuring section of the patient terminal consists of an optoelectronic insulation interface and converter section placed on the motherboard of the patient terminal. The DAS circuitry consists of a second-stage 16-channel analog multiplexer, a programmable gain amplifier (PGA) and a 12-bit A/D converter. The optoelectronic insulation interface is created by set of high-speed 4kV optocouplers for transmission of control and data signals over the insulation barrier between the measuring and interface section.

Interface section of the patient terminal contains 8-bit micro controller (Atmel 89C2051) with supporting logic in a Lattice programmable array, 16 KB FIFO memory for data buffering during the fast data acquisition and an IEEE1284 parallel port controller (CL

CD1283) for interfacing to the PC. The whole measuring procedure is pre-programmed through the parallel port in a 256-channel sequencer. Sequence of control signals for channel switching, individual gain control for all channels, for setting of sampling frequency and cut-off frequencies of ECG filters is stored in the sequencer memory. After the measurement is started, all operations are performed autonomously and measured data are transferred in DMA mode through the parallel port into the PC.

4. Application software

Modular set of application programs enabling ECG data acquisition, processing, presentation and archiving was developed for the Cardio 7 mapping system. It is running on DOS or Windows 95/98 platform with at least 2 MB of free disk and RAM memory and consists of several independent but cooperating applications:

- data management and system setup - enables manipulation and retrieval of recorded and computed data and configuration of the software to user needs,
- multi-channel ECG recording with real time monitoring - (runs in DOS mode only) enables measurement of standard 12-lead ECG, Frank VCG and/or up to 128 chest leads for BSPM using different lead sets and sampling rates (usually 1, 2 or 4 ms),
- ECG processing and display - enables automated and interactive signal processing: ECG filtering, baseline correction, measurement of times and amplitudes, marking of important time instants in signals, etc.,
- body surface potential mapping - displays instantaneous maps of surface potentials, enables to view also the dynamics of potential distribution,
- integral mapping - presents desired time integrals of measured surface potentials,
- departure integral mapping - computes typical templates of surface integral maps and displays departures of patients' maps from these templates,
- isochronal mapping - presents body surface distribution of characteristic time instants and intervals obtained from measured ECG signals.

In all mapping programs, corresponding surface maps are computed and displayed or printed in numerical or graphical form and in various formats and colors.

The software package is open to future extensions and all data formats are public and enable the user to use the data in own applications. Examples of information displayed during ECG processing and in departure integral mapping are shown in Fig.2 and Fig.3.

5. Results and conclusions

The new device was used for ECG mapping in studies needing high-resolution data recording. In the first one [3], body surface potential maps and activation-recovery interval mapping were analyzed as tools for assessment of local heart repolarization properties. In the second one [4], relation between ST-T abnormalities and late potential parameters after coronary intervention has been studied using potential and departure integral maps. Currently the system is experimentally used in the hospital of the Comenius University Medical School in Bratislava.

Experience with the systems shows that despite the complexity of the measuring process due to increased number of measured ECG leads, the system is able to supply more detailed and diagnostically interesting data about the human cardioelectric field.

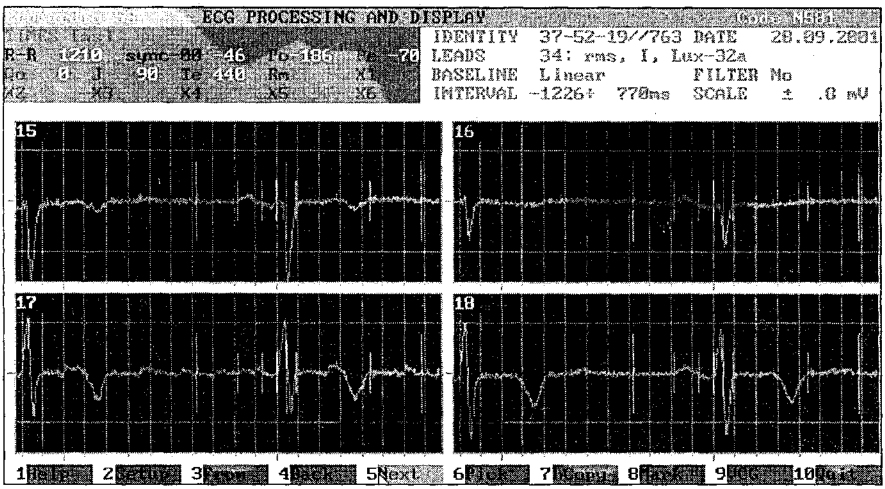

Fig. 2: During ECG processing, selected ECG signals can be displayed or printed in desired format, times and amplitudes can be read and important time instants can be interactively marked in the signals.

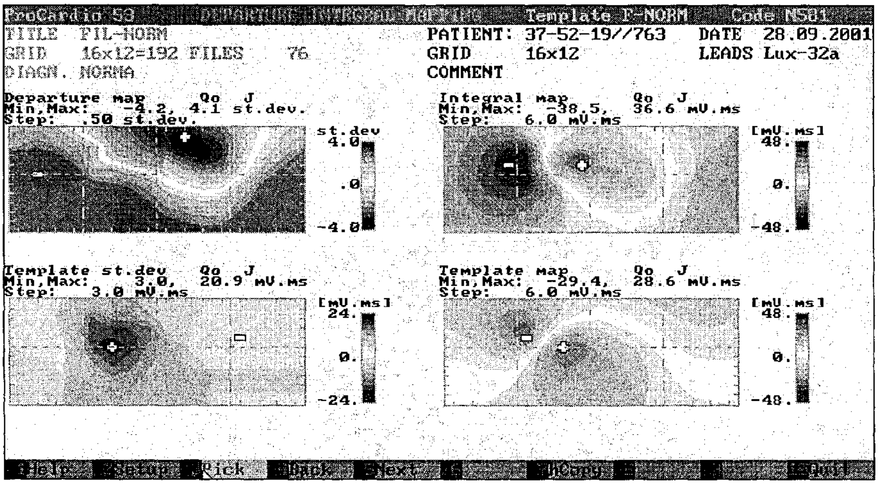

Fig. 3: In departure integral mapping, departures of patient integral map (upper right) from a template map (lower right) are displayed. Differences in the departure map (upper left) greater than a selected threshold (usually -2 standard deviations) are marked by different color.

Acknowledgment

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