Portable High Resolution Multichannel ECG Measuring Device

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Abstract. *Advanced electrocardiographic diagnostic methods of various cardiovascular diseases need high resolution multichannel measurement of ECG signals that offer much more information than the standard 12-lead ECG. To obtain such ECG signals in required quality a special multichannel electrocardiograph ProCardio 8 was developed. The system is designed as a virtual instrument consisting of an external intelligent measuring unit connected via optical USB interface to a controlling PC running the measuring and data analyzing software. The system can be configured for measurement of up to 144 standard and/or mapping ECG leads using active or passive Ag-AgCl or carbon electrodes. Most of the measuring and newly designed data processing software is written in MATLAB and its compiled version can be deployed as a stand-alone application on any computer running Windows. The modular software architecture consists of real–time modules for the control and checking of the measuring system, data acquisition and signal monitoring as well as modules for off-line data analysis including ECG processing, body surface potential mapping, integral mapping and data preparation for non-invasive model-based electrocardiographic imaging based on inverse solutions and serving as an advanced diagnostic tool.*

Keywords: Intelligent ECG Measuring System, Multichannel Data Acquisition, Body Surface Potential Mapping, Non-invasive Identification of Local Ischemia

1. Introduction

High resolution multichannel measurement of surface ECG signals and computation of body surface potential maps (BSPM) is a non-invasive procedure used in electrocardiographic diagnostics that enables detailed analysis of cardiac disorders based on 24 to 256 ECG leads that offer much more information on the physiological state of the heart than the commonly used standard 12-lead ECG. Measured ECG signals and BSPM can be used for immediate analysis and diagnostics. However, many studies suggest that BSPM together with information on torso geometry and electrical structure obtained from imaging techniques such as MRI or CT can be used for advanced diagnostic methods enabling non-invasive assessment of abnormal configuration of electrical sources in the heart. [1]. In this paper, a powerful high resolution measuring system that can be used for advanced BSPM based cardiac studies is presented and its ability to non-invasively localize small ischemic regions is demonstrated.

2. Material and Methods

Based on the long term experience with multichannel measuring systems [2] a battery-powered high resolution ECG mapping system ProCardio 8 has been developed. The system enables measurement and processing of ECG signals needed for diagnostics based on BSPM and provides input data for solution of the inverse problem of electrocardiology.

Hardware of the ProCardio System

The measuring system (Fig. 1) consists of a set of ECG electrodes, intelligent measuring unit and a personal computer that controls the data measurement, processing and analysis. ECG signals can be sensed by disposable Ag-AgCl or carbon electrodes that can be connected to active or passive adapters. The use of active adapters helps to reduce the noise in measured ECGs, passive adapters in combination with carbon electrodes and lead wires offer the possibility to use the system during CT examinations. The basic electrode configuration consists of individual electrodes that enable universal configuration of leads. However, for faster electrode application also the use of strips with several electrodes is possible.

The measuring unit is placed in a patient terminal box that is connected to the USB port of the host PC by an optical cable with USB interface. The unit contains an amplifying and measuring subsystem powered by rechargeable Li-ion battery. The system enables recording of up to 128 ECG signals from unipolar chest leads and 4 to 16 standard limb or chest leads. The system is modular and each input module includes 16 analog channels connected to two robust 24-pin Centronix connectors. One input module is used to record signals from R, L, F leads and contains also the circuits for active neutralization of the patient using a DRL (driven right leg) electrode that minimizes the common mode signal. All signals are measured relatively to a special CMS (common mode sense) electrode that can be placed so that the overall noise in ECG signals is minimized. Each measuring channel is equipped by a DC-coupled ECG amplifier with a fixed gain of 40 and a 22-bit σ-Δ A/D converter. Sampling frequency can be set between 125 Hz and 2 kHz per channel. The data acquisition system is controlled by a 16-bit microprocessor. Commands for selection of measured channels, formatting of the digitized data and checking of correct function of the unit are received from the controlling PC. Data sampled from the analog channels are streamed via four serial DMA-controlled UART channels to an USB FIFO chip and optical USB interface that provides bidirectional data transfer between the measuring unit and the controlling PC with the data rates of up to 1 MB/s.

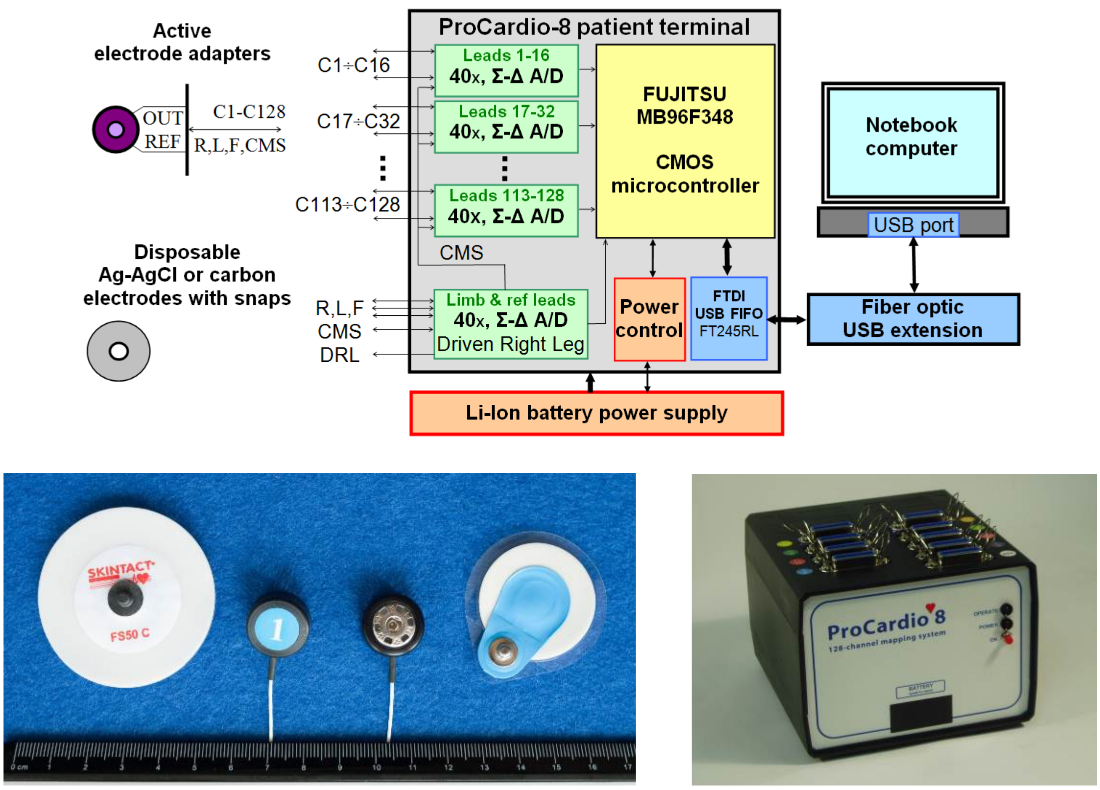

Fig. 1 Block scheme (top) and view (bottom righ) of the high-resolution multichannel measuring device ProCardio 8. The system can use passive or active 2-wire electrode adapters with both, Ag-AgCl and carbon disposable electrodes (bottom left).

ProCardio Software Architecture and Mmodules

The application software of the ProCardio-8 system was designed as a Matlab application consisting of separate tasks controlled by individual sets of parameters stored in global variables. After the application start, they are loaded from system configuration files, can be individually modified by each user and saved on disk for future use.

The **real-time measuring software** has two main modules (Fig. 2): 1) testing of electrode contacts and signal properties and 2) signal recording and monitoring. The first module is executed before each ECG recording. Electrode contacts are checked by measurement of the electrode-skin polarization voltages. Simultaneously, offsets and amplitudes of ECG signals in all channels are analyzed and this information is used for subsequent setting of measuring channels. The module is terminated after successful electrode and signal testing. The second module includes functions for the low-level control of the measuring unit, data transfer between the measuring unit and the PC, for visualization of measured signals in desired format on the PC screen and functions for storing of the recorded data on the hard disk.

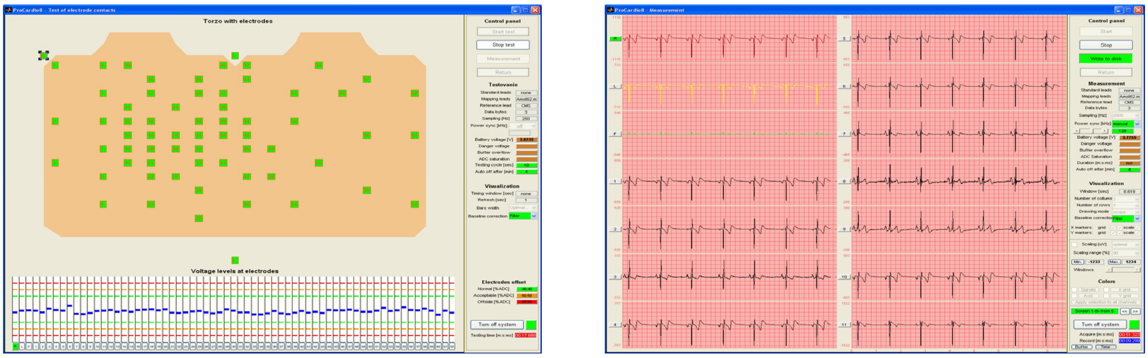

Fig.2. The real-time control and data acquisition software. Left: Checking of all electrode contacts, signals and measuring unit parameters. Right: During the ECG recording the measuring unit parameters and ECG signals can be monitored in desired format.

The **off-line ECG signal processing and analysis** enables the user to process the stored ECG signals and to compute several types of body surface maps. Typical tasks of the signal processing are filtration, baselines wandering corrections, signal averaging and identification of waves and instants in the ECG signals. ECG data from selected time instants or intervals are then used for computation of body surface potential maps and integral maps (Fig. 3, left). Departure integral maps displaying the departures of patient integral map from selected template (expressed in standard deviations) can be used for direct cardiac diagnostics. Difference integral maps revealing the changes in patient maps e.g. due to ischemia can be used for noninvasive model-based localization of the affected cardiac tissue (Fig. 3, right) [3].

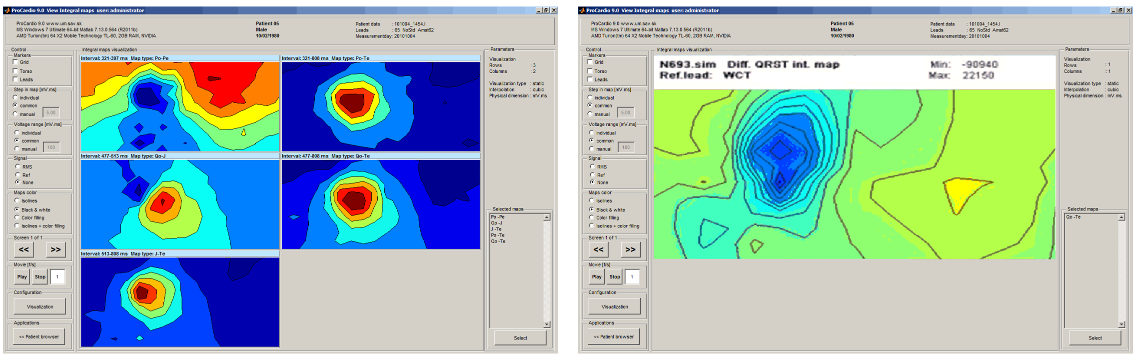

Fig. 3. Left: Example of normal body surface integral maps (for intervals P, PQRST, QRS, QRST and STT). Right: QRST difference integral map with negative area indicating ischemia in anterior wall of the LV.

3. Results

Difference integral maps recorded at rest and after a stress test from 62 leads in patients with one or two ischemic lesions were used to solve the inverse solution and identify one or two ischemic lesions represented by dipoles. In 8 evaluated patients the obtained results were in agreement with SPECT images and identified 2 lesions in 3 patients and 1 lesion in another 3 patients. For remaining 2 patients no local ischemic lesions were identified what was in agreement with SPECT results. Example of the inversely located dipoles in a patient with 2 lesions located at the base on the anterior wall of the left ventricle and in the middle part of the inferior wall is shown in Fig. 4.

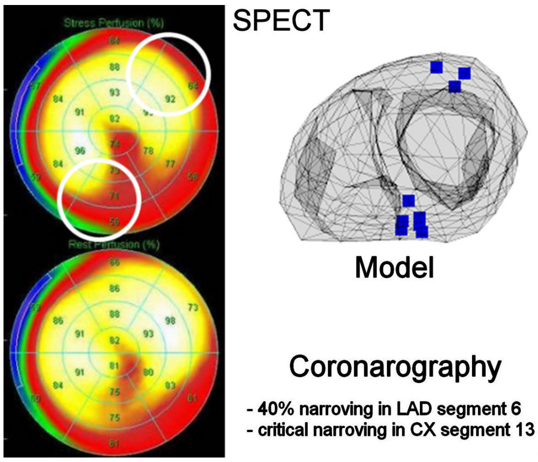

Fig. 4. Comparison of the localization of a double ischemic lesion based on BSPM with SPECT and coronarography results

4. Discussion and Conclusions

The introduced the ProCardio 8 system is intended for BSPM with 64 or more leads. Despite it enables direct cardiac diagnostics based on maps, our previous attempts to detect local ischemic regions by using departure integral maps [4] showed that changes in BSPMs in many cases can hardly be detected. The newer results using model-based approach indicate that this method and the presented device provide promising tools for identification of the presence of local ischemia during exercise. Our current results are based on using BSPM and a general model of the torso geometry. The use of patient individual torso could further improve the accuracy of the ischemia identification [5]. Hence also the possibility to create patient torso model from CT or MR data will be included in the ProCardio software in the future.

Acknowledgements

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