Portable Device for High Resolution ECG Mapping

V. Rosík, S. Karas, E. Hebláková, M. Tyšler, S. Filipová

Department of Biomeasurements, Institute of Measurement Sciences, SAS,
Dúbravská cesta 9, 841 04 Bratislava, Slovakia
Email: umerrosi@savba.sk

***Abstract**. Portable device for multi-channel ECG measurement and body surface potential (BSP) mapping is introduced and its possible application for cardiac diagnostic is presented. The device is designed for simultaneous measurement of up to 144 body surface potentials relatively to a relocatable reference electrode. Use of active electrodes, driven grounding electrode and battery operation of the device facilitate optimal signal quality. Microprocessor controlled data acquisition unit is placed in a patient terminal and connected to the USB port of a hosting personal computer through an optical extension cable that minimizes capacitive coupling and guarantees high level of patient safety. Modular software for ECG recording and monitoring and for off-line ECG processing and BSP mapping was developed in Matlab environment. The device was used for testing of non-invasive identification of local ischemic lesions based on maps of BSP integrals and on dipolar model of the cardiac electric generator.*

Keywords: multi-channel ECG measuring system, active ECG electrodes, body surface potential mapping, noninvasive identification of ischemic lesions.

1. Introduction

Body surface potential (BSP) mapping is a non-invasive electrocardiographic method enabling more precise diagnostics of cardiac diseases. It is based on registration of cardiac potentials using 24 to 240 sensing electrodes and on construction of detailed potential distribution on the body surface. Information content in BSP maps is greater than that of commonly used standard 12-lead ECG or Frank VCG that sample the surface potential only in a few selected points. Direct visual and quantitative analysis of measured BSP maps can be used to obtain valued diagnostic information. Using advanced methods for inverse solutions and model of the cardiac generator, BSP maps together with information on torso volume conductor can serve for non-invasive computational assessment of abnormal electrical sources in the cardiac tissue. In this paper, a newly developed high resolution ECG mapping device is introduced and its use for non-invasive assessment of local ischemic lesions is presented.

2. Methods and results

ECG mapping device

Based on previous experience with BSP mapping devices [1], concept of a battery powered ECG mapping system ProCardio-8 was developed. It enables to acquire high quality multi-channel ECG recordings and to construct BSP maps suitable for direct cardiac diagnostics or as input data for inverse solutions. The device consists of a set of active electrodes, a data acquisition system and a hosting personal computer used for measurement control, processing of measured data and their analysis and electrophysiological interpretation.

ECG signals are sensed by active electrodes formed by disposable passive Ag-AgCl electrodes attached by electrode snaps to active adapters (Fig.1). Each electrode adapter is made in SMD technology and contains a thermally compensated amplifier (Analog Devices

Fig. 1. Active electrodes are composed of quality Ag-AgCl disposable electrodes and active electrode adapter.

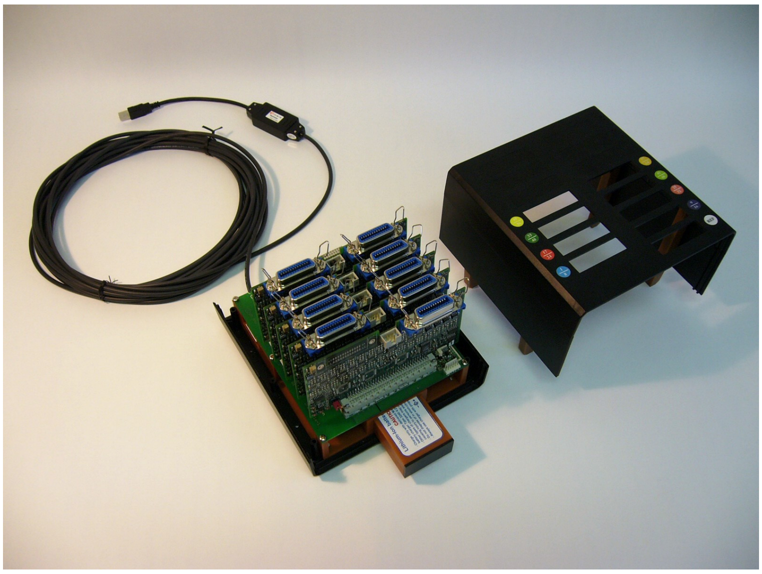

Fig. 2. ProCardio 8 electronics for 64+4 measuring channels in the patient terminal with Li-ion battery and optical USB extension cable.

OP 193). Its high input and very low output impedance effectively reduces disturbing signals often induced in electrode cables. Use of quality disposable Ag/Ag-Cl electrodes guarantees low noise, minimal polarization potentials and eliminates risk of patient infections.

The data acquisition system is placed in a patient terminal box and connected to the USB port of the host personal computer. Its small geometric dimensions (14x19x20 cm) help to minimize capacitive coupling with the environment in the exami-nation room. The data acquisition system is currently configured to record ECG signals simultaneously from 64+4 leads and is expandable to 128+16 leads (Fig.2).

The data acquisition system is modular and built from several measuring boards plugged into a motherboard containing the microcontroller and switched power supply module. Each measuring board has 16 input analog channels connected to two robust 24-pin Centronix connectors. One of the boards is configured as the reference board and is equipped with additional circuitry for a common mode sense electrode (CMS) and driven right leg electrode (DRL). It is also used for recording of signals from limb leads R, L and F. Potential of the Wilson's central terminal (WCT) which is computed as the mean value from the limb electrodes and commonly used as the reference for all unipolar leads can be generated from the limb leads by a resistor network and sampled along with the limb leads signals. This facility allows to speed-up computation of unipolar leads in real time. Remaining 12 channels on the reference board can be used for additional unipolar leads or can stay unpopulated.

In the hardware, all signals are measured relatively to the CMS electrode that can be attached to the patient’s body so that the interference from the common mode is minimal. The DRL electrode is used to provide “active grounding” of the patient and further reduces the common mode voltage. Current limiting resistor in the DRL circuit protects the patient against possible electrical defects in the amplifiers. In case that some active electrode would break down and become shorted to the power supply voltage, DRL circuitry limits the maximum error current to 50 μA which complies with the value specified for the IEC-601 CF type isolation used in Europe. Value of the resistor can be changed to achieve maximal current of 10 μA and to comply with the US standards. Additional patient protection in the data acquisition module prevents stray current to flow steadily through the patient body. If the stray current is close to ±50μA this protection circuit generates an power-down signal causing that the microcontroller disables the power supply.

Each measuring channel is equipped with a DC-coupled instrumentation amplifier (Analog Devices AD 627) with a fixed gain of 105 and a 22-bit Δ-δ A/D converter (Analog Devices AD 7716). Sampling frequency can be selected in the range between 125 and 2000 Hz resulting in effective dynamic converter resolution between 19 and 16 bits.

The data acquisition system is controlled by Fujitsu MB96F348TS microcontroller. Its 3V power supply with internal regulator offers advantageous solution in terms of electromagnetic interference and power consumption. On chip flash memory gives enough space for the controlling software. Four UARTs and a DMA controller are used to manage the multi-channel measuring unit and to communicate with the host PC. Microcontroller streams the serial data from sampled analog channels and sends them to the host PC. Selection of measured channels and proper formatting of digitized data with several possible byte lengths is controlled by commands received from the host computer.

Communication with the host PC over an USB FIFO circuit (FT 245R from FTDI) provides bidirectional data transfer with rates of up to 1 MB/s. To further minimize the capacitive coupling between the patient terminal and the host PC a fibre optic USB extension cable is inserted between the patient terminal and the USB port of the host PC. The optical fibre link together with battery power supply of the patient terminal provides complete patient safety with leakage currents well below the permitted limits.

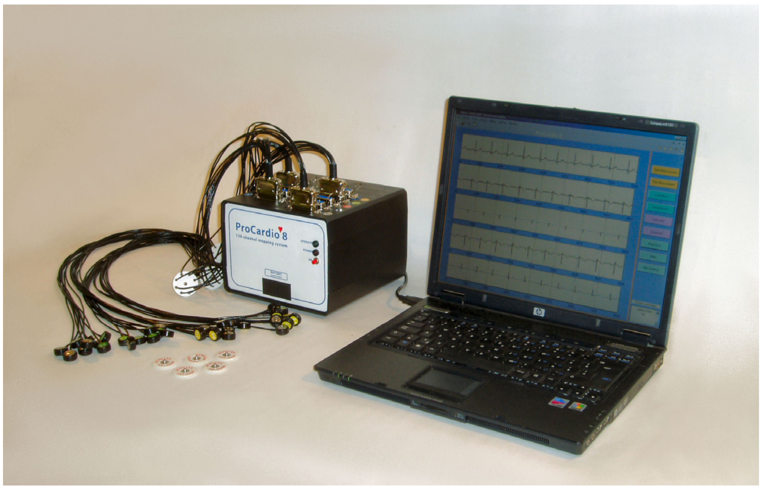

Fig. 3. Photo of the ProCardio 8 mapping device.

The patient terminal is powered by a rechargeable Li-ion battery module. Due to the advanced power management controlled by the on-board microcontroller the system can work at least one working day before the battery has to be replaced or recharged.

Application software

ProCardio 8 application software for PC is running under Windows/XP. Real-time ECG data acquisition program sets the working mode of the data acquisition system, reads the data stream with measured ECG signals from selected channels, simultaneously displays them on the PC screen and stores them on disk. The test routine which checks the electrode contacts is implemented and can be activated by the user before each measurement. Measured and processed data are stored as GDF files (general data format for biosignals) in selected directory.

The application was developed in Matlab environment. Using its ability of generic DLL calling, communication with the USB port is based on the external D2XX driver that consists of a Windows WDM driver (communicating with the USB FIFO in the mapping device via the Windows USB stack) and a DLL library of functions (interfacing the PC application software to the WDM driver) [2]. Implementation of an external hardware driver enables effective use of its library functions [3]. Example of the user interface of the data acquisition program with 24 monitored ECG signals is shown in Fig. 4.

Fig. 4. Screen shot of the ProCardio 8 measurement window with monitored ECG signals from 24 leads. The contents and format of the window can be adjusted according to user requirements.

The user can set the screen format to see 1 to 64 signals simultaneously and to scale each ECG channel independently, so the best view of measured signals can be achieved. Some useful information, such as the selected lead system, reference lead, elapsed time, sampling frequency, etc. are displayed on the right side of the main panel. On the left side of each ECG signal there is an identification tag that is also used as a control button enabling to select a desired channel for individual setting.

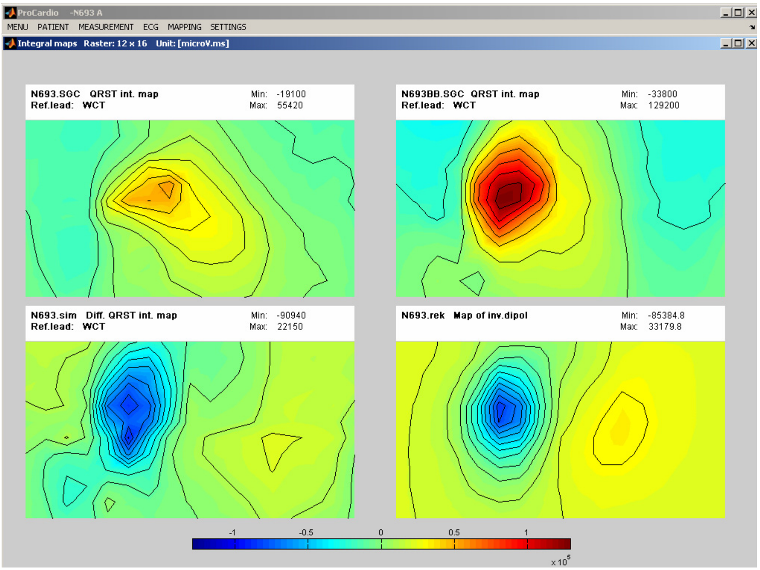

Fig. 5. Surface QRST integral maps of a MI patient. Left part of each map represents anterior chest surface and right part the back. Maps before (top left) and after coronary intervention (top right) are shown. Their difference (bottom left) represents changes in the surface electrical field that are caused by some reduction of the ischemic lesion. In many cases, these changes can be satisfactorily approximated using a dipolar electrical generator (bottom right). Its position and orientation can be used to indicate the site and type of the changed myocardial region.

Data acquisition is followed by off-line data processing and evaluation. Preprocessing of ECG signals, mapping of body surface potentials and their time integrals and optional model-based diagnostic evaluation of the obtained maps are included. 2D or (on torso) 3D presentation of the maps is possible.

In Fig. 5 there is one example of surface integral maps of the QRST interval with and without manifestation of ischemia. Their difference can be interpreted as caused by pathological local source due to the changed repolarization of ischemic myocytes. Using a dipole model of the source and information on the torso volume geometry and electrical conductivities, location of the ischemic lesion and its properties can be estimated.

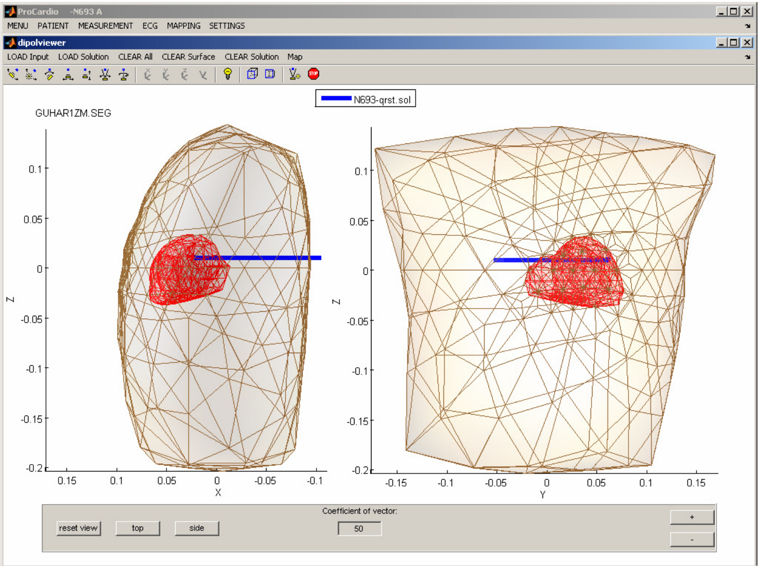

Fig.6. Result of non-invasive localization of an area with changed repolarization of the myocardium in a MI patient after successful coronary intervention. Solution was obtained from differences in surface QRST integral maps before and after the treatment and model of the torso volume conductor. Single dipole model was used as an equivalent generator representing locally changed electrical properties of the myocardium. Position and orientation of the equivalent dipolar generator is marked by a blue line.

In Fig. 6 there is some result of a dipole model based non-invasive localization of the site of local repolarization changes in the myocardium in a patient after myocardial infarction. The patient underwent successful coronary intervention on single vessel [4].

3. Discussion

Several hardware and software alternatives were considered during the device development, e.g. Ethernet (including wireless) versus USB interface between the device and PC or Matlab versus LabView software for real time measurements, to name just a few of them. Presented design offers required properties and parameters with the use of available technological, software and human resources. Modularity of the whole design enables to change partial hardware and software components if more advanced tools are available.

4. Conclusions

Availability of a high resolution measuring device is necessary prerequisite for thorough experimental testing of non-invasive diagnostic electrocardiographic methods that are being investigated in cooperation of engineering and medical institutions. First experience with the ability of the developed device to provide long term low noise multi-lead ECG data proved correctness of the design. However, to exploit its full potential and prepare it for work in clinical environment, completion of the user friendly interface and full integration of the developed diagnostic methods into the device is desirable.

Acknowledgements

This work was supported by grants 2/7092/27 from the VEGA grant agency and APVV-51-059005 from the APVV agency.

References

[1] Rosik V, Tysler M, Jurko S, Raso R, Turzova M 2002 Cardio 7 - Portable System for High Resolution ECG Mapping *Studies in Health Technology and Informatics.* **90,** 41-46
[2] D2XX Programmer's Guide. Future Technology. Devices International Ltd., 2005
[3] Hanselman D., Littlefield B.: Mastering Matlab 7. Prentice Hall, 2005.
[4] Tyšler M., Turzová M., Švehlíková J., Hebláková E.: Noninvasive identification of ischemic lesions in the heart. *Advances in Electrical and Electronic Engineering*, **4**, 2005, 124-127.