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Plug-in circuit board for the Raspberry-Pi microcomputer to reproduce multi-channel original electrocardiograms

Abstract: Commercial simulators can only reproduce electrocardiograms (ECG) of the normal and diseased heart rhythm in a simplified waveform and with a low number of channels. With the presented project, the variety of digitally archived ECGs, recorded during electrophysiological examinations, should be made usable as original analogue signals for research and teaching purposes by the development of a special printed circuit board for the mini-computer “Raspberry-Pi “.

Keywords: Electrophysiology, ECG, Electrocardiogram, Simulator, Raspberry-Pi, Research, Teaching.

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1 Introduction

Evaluation of electrocardiograms (ECG) is of great significance in diagnosis and treatment of cardiac arrhythmias. Different ECGs can be recorded with electrocardiographs from the body surface using adhesive electrodes on the skin. Additionally, as part of electrophysiology (EP) studies, recording and evaluation of electrograms directly from the heart is done by invasive procedures using epi- and endocardial electrode catheters. If several electrode catheters - mostly inserted via veins - are guided to certain positions in the heart, the excitation can be understood and assessed. In cases of cardiac rhythm disorders, these recordings provide detailed information about the origin and propagation of arrhythmias, allowing targeted treatments with either implantable pacemakers, defibrillators or catheter ablation.

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ECG simulators are commercially available for basic research and training applications. Unfortunately, all of them only provide synthetic ECGs of normal and diseased heart rhythms as simplified morphologies with small variations and number of channels, thus being sufficient for simple teaching purposes. Their disadvantage is that they can not provide the individual diversity observed in clinical routine. To explain and study more sophisticated electrophysiological problems or even for testing of new detection algorithms of cardiac implants, such as pacemakers, defibrillators or event recorders, the simulation of individual ECGs of rhythm episodes actually observed in real patients is required.
For example: A current problem of implantable defibrillators and resynchronization systems is still the delivery of so-called *inappropriate shocks*, which are caused by a rhythm episode misinterpreted as life-threatening ventricular fibrillation by the detection-algorithm of the device. Thereafter, the device automatically applies a painful high-energy electroshock to the patient in order to terminate the assumed arrhythmia. This problem is an important aspect concerning the quality of life of the patients, since many suffer very much from those inappropriate shocks.

2 Aims

As part of the conception and realization of didactic solutions for the creation of novel, problem- and action-oriented teaching and training systems enabling physicians, medical technicians and corporate staff an effective in-vitro training in the electrotherapy of the heart, we aimed to reproduce original intracardiac and surface ECGs of rhythm episodes, recorded during EP studies in order to make them usable as true-to-life analogue signals for sophisticated teaching purposes. With the possibility of selective reproduction of simultaneously recorded multichannel ECG, it should also be used as mighty research tool in further development of diagnosis and therapy of cardiac arrhythmias at the Peter Osypka Institute for Pacing and Ablation.

3 Methods

The full spectrum of various normal and diseased heart rhythms can be found in ECG recordings of real patients that underwent invasive EP studies. Therefore we used selections of routinely recorded intracardiac and surface ECGs registered with a Bard Electrophysiology Lab System (EP Lab) and digitally archived on magneto-optical disks or CDs. For analogue reproduction of those digital multi-channel recordings we chose a Raspberry-Pi (RPi) Single Board Computer (SBC) [1–2] due to its manageability, price and low volume.

Initially, software was developed to select and extract sets of simultaneously registered intracardiac and surface ECGs containing interesting rhythm episodes from the EP Lab recordings, assemble them into endless loops and to export it on a SD-card as binary file for subsequent data-processing and modification (e.g. level adjustment) with the RPi. The digital ECGs are then reconverted into analogue output signals on a special developed plug-in circuit board, fitted for the RPi.

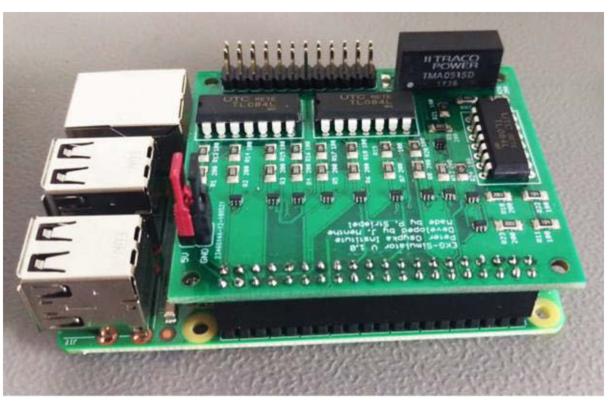

Figure 1: Plug-in “Piggyback-Board” on a Raspberry-Pi Single Board Computer

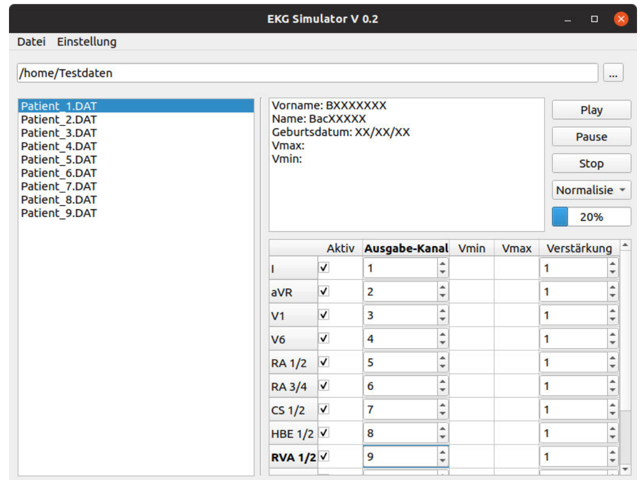

Figure 2: Graphical User Interface of the Raspberry-Pi based true-to-life ECG Simulator.

For digital-to-analog conversion (DAC) and signal output, a *piggyback board* (Figure 1) was developed for the RPi using the Autodesk Eagle program. It was designed with the aim of minimizing electromagnetic interferences using SMD technology and a shielding ground polygon. For this reason, Texas Instruments DAC8411 SMD digital-to-analog-converter chips measuring only 2 x 1.2 x 1 mm were used [3]. To adapt to the desired output voltage, three quadruple operation amplifiers in conventional DIL14 packages were arranged following the 12 DACs (Figure. 3). Its operating voltage is provided by a TMA0515S isolated DC/DC converter. Assembly of the board was done manually in the SMD laboratory, using reflow soldering technique.

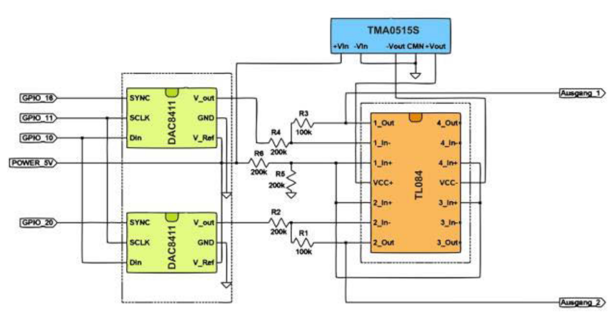

Figure 3: Excerpt of the circuit diagram; 2 channels of the designed board for analogue reproduction of 12 simultaneously registered and digitally archived original patient ECGs.

4 Results

For the intended applications, the number of analogue ECG signals to be simultaneously output as infinite loop, was initially limited to 12. Combination of the reproduced multichannel ECG can be changed and adjusted using a menu program with graphical user interface (Figure 2), specially created for the RPi.

As an application example, Figure 4 shows the reproduction of the electrograms 1 and 2 recorded from a patient during an EP study from the body surface, 3 and 4 from the right ventricle and 5 from the right atrium as analogue output signals. This is the case of a patient with a reported sudden loss of consciousness (so-called syncope), due to an episode of ventricular tachycardia [4] induced by means of a clinical provocation procedure. Thus, the suspected diagnosis could be proven.

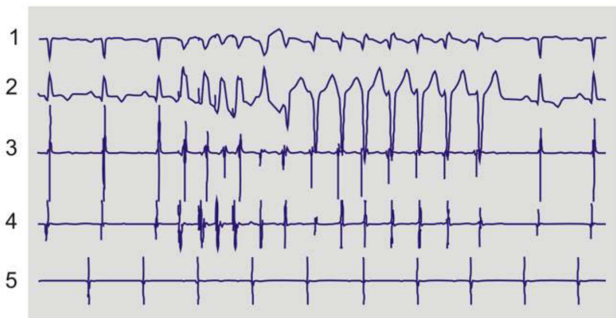

Figure 4: Reproduction of original digital electrocardiograms as analogue signals using the example of diagnostic provocation of a ventricular tachycardia. See text for details.

5 Conclusions

Simultaneous true-to-life electrograms that run in real-time in an infinite loop can be used not only for the training of physicians and the medical technicians supporting them. They are also of interest in the development, optimization and testing of algorithms for the automatic detection and differentiation of life-threatening arrhythmias and their adequate electrical treatment with implantable defibrillators. Especially for this purpose, the use of the great variety of electrocardiograms recorded during electrophysiological studies can be useful and helpful.

Author Statement

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