PATRES – A Mobile Patient simulator for Resuscitation Training

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Abstract: Resuscitation training has to be performed under conditions as realistic as possible. This includes both the usual measures in cardio-pulmonary resuscitation (CPR) and advanced measures, e.g. the use of Automatic External Defibrillators (AED). Currently available ECG and patient simulators either do not meet the requirements of modern training for medical professionals and laymen, or are much too expensive. PATRES is a mobile, PDA-based ECG simulator, which overcomes the restrictions of normal ECG simulators, is significantly cheaper and easier to handle than high-end patient simulators. It opens new opportunities for a new and modern resuscitation training with its wireless transmission of simulation data.

1. Introduction

Resuscitation is a very critical process. For its success it is vital that medical staff as well as medical laymen have been extensively trained under conditions as realistic as possible. This includes not only CPR measures (breathing and chest compressions), but also defibrillation, which is the only effective measure to end life-threatening cardiac fibrillation. Especially the training of laymen with so-called AEDs, as supported by the Bundesärztekammer [BÄK01], is a now evolving challenge for most rescue organisations: Many people have to be trained in a rather short time. For professional training in most organizations, the same equipment is used time after time due to cost reasons. In this situation, the requirements are much higher: The simulation has to be more realistic and a great variety of different resuscitation scenarios is needed to enhance the training's quality. The simultaneous simulation of different physiological parameters besides the ECG would be welcomed by most trainers.
Transportable ECG simulators in the size of a paperback book are usually used for training with AEDs and conventional defibrillators. These devices can put out only a few different ECG rhythms and have to be plugged directly into the monitoring device instead of the normal defibrillation electrodes. Table 1 shows an overview of several available ECG simulators. The trainer usually has to hold the simulator in his or her hand

to change between different rhythm types manually, resulting in two major problems during training progress:

- Pauses or irritations may occur during training if a rhythm change does not take place synchronous to an actual event
- The mobility of the trainer is rather limited, which may have negative effects on the quality of the training if tips or demonstrations are necessary

Supplier	**Product name**	**No. of rhythms**	**Price**	**URL**
Ambu	EKG-Box	26	500€	www.ambu.de
Laerdal	Heartsim 200	30	n. a.	www.laerdal.de
WorldPoint ECC	Interactive ECG Simulator	34	625 US$	www.worldpoint-ecc.com
Medtronic	Quik-Combo (1, 3, 12 Leads)	5-7	425-725 US$	www.physiocontrol.com

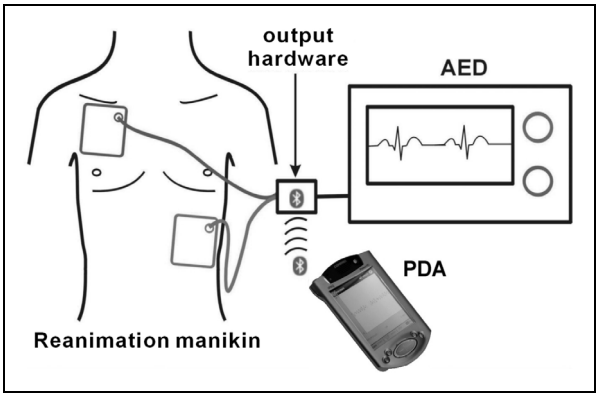
Table 1: Overview of available ECG simulators

There are also high-end patient simulators available [HM02], but due to their high costs, they cannot be used in the training of large groups.
A solution for the upper-mentioned problems can be a mobile simulator. This device can automatically detect events like the administration of a defibrillating shock, and can change rhythm automatically according to pre-programmed scenarios. This article presents a mobile, PDA-based ECG simulator which has the following outstanding features compared to others:

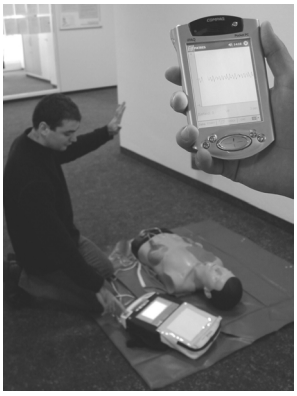
- wireless transmission of ECG data from the PDA to the output hardware via Bluetooth™
- automatic reaction to events and timing conditions according to pre-programmed scenarios
- use of public databases as a source for realistic ECGs
- easy-to-handle interface for the programming of scenarios

2. System Concept

A PDA is used for storing ECG data, and the user interface for choosing cardiac rhythms and programming scenarios for resuscitation training. After starting a simulation, the ECG data is transmitted to the extension hardware over the PDA's integrated Bluetooth™ module and is then outputted to the connected AED. The extension hardware detects an applied shock and transmits this information over the wireless interface to enable the PDA to correctly react to events.



a)



b)

Figure 1: a) System concept of PATRES: PDA, Bluetooth™ link and output hardware interposed between defibrillation electrodes and AED. b) Application example

This wireless connection is one of the key features of the PATRES system. It allows the trainer to not have to worry about intervisibility between the central unit and the output hardware, so that he can freely move around and can fully concentrate on the progress of the training and the supervision of his trainees. Using Bluetooth™ will make it possible to establish a pico-network, with the PDA as a master and several outputs as its slaves, and thereby will allow several training sites to be controlled in parallel. This modern education method is currently only possible with either a very high amount of equipment, or intensive interaction with the trainer.

Another key feature of the patient simulator is the opportunity to conduct training with individual, programmable scenarios. The trainer is provided with a programming interface, where he or she can create scenarios in a "finite state machine". "States" are several selected ECG rhythms, while transitions between them are initiated by events (applied shock etc.) or timing issues (e.g. transition from one rhythm to another after a certain amount of time). This information is stored in an XML document. A GUI must be provided that enables the user to view given scenarios and to develop his own.

During training, the trainer must have the opportunity to take notes and mark special events, like the beginning of CPR, intubation etc. to log the process of the training. He can be supported by an automatic log of occurrences of defibrillation shocks by the PATRES system. This log file can then later be evaluated, and used to optimize the medical staff's performance, to reveal mistakes during treatment and to better judge the quality of resuscitation.

To meet future requirements, the system should be not only be able to provide ECG signals, but also other physiological signals. This is because it is very likely that AEDs in the future will make their decision to shock not only by analysis of the ECG, but also by simultaneous analysis of the thorax impedance, the saturation of blood oxygen (SpO_2), judgment of acoustic breathing signals etc. Therefore, future patient simulation systems should be able to simulate these signals as well. The simulation of these parameters is sometimes very difficult to realize, however, if original resuscitation equipment, like SpO_2-fingerprobes etc., are used. In any case, these requirements should be taken into account during future development.

3. Materials and Methods

The PDA is a Compaq iPAQ H3870 with an integrated Bluetooth™-module. The Texas Instruments Mixed Signal Processor MSP430F149 was chosen for controlling the output hardware because of its low power consumption. It has a very comprehensive set of I/O modules like a 12bit A/D converter or PWM outputs. The WML-C09 module from Mitsumi has been used as the Bluetooth™ communication device in the output hardware.
As a source for ECG data, the following ECG databases [Phy03a] can be used, which are widespread and freely available:

- MIT-BIH Arrhythmia Database
- CU Ventricular Tachyarrhythmia Database
- MIT-BIH Noise Stress Test Database

A comprehensive waveform database (WFDB) software package exists for workng with these databases, which can be used under the GNU Public License (GPL). The library is written in ANSI C, and provides methods for handling ECG data sets stored in the so-called MIT/BIH format. The application itself was developed in C/C++ for the Windows Pocket PC 2002 operating system.
XML is used for storing the scenario information programmed by the user. XML is a meta language which enables the user to define his own markups document formatting. It allows the structured representation of data, and therefore is well suited to represent the state chart of programmed resuscitation scenarios.

4. Results

The WFDB software package has been modified and adopted for the use under Pocket PC 2002, so data files from the databases mentioned above can be read according to the loaded scenario. The application flow of the scenario is stored in an XML document, which is easy to understand due to its hierarchical structure. An example of a scenario and parts of its XML representation can be seen in Figure 2. Programming of custom scenarios on a text based level is, therefore possible and can easily be learned. A SAX parser is used to extract the data from the document and store the relevant parameters in dynamically generated data objects. Relevant parameters are: rhythm class, state number, ECG data set to be used, start and end of used data frame, jump conditions (at the moment: number of applied shocks and timeout condition) and jump target states. The scenario can be viewed “offline” on the PDA itself by navigating through the scenario via software buttons. In the “online” state, when data is really transmitted to the output hardware, the scenario can be controlled automatically by the PDA.

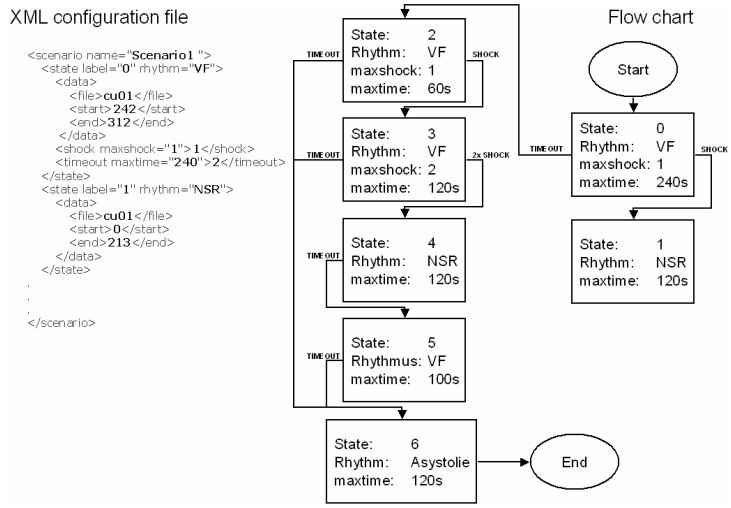


Figure 2: Flow chart of a resuscitation scenario and ist XML-representation

A bi-directional communication protocol between the PDA and the extension hardware has been defined and implemented. The wireless link galvanically separates the PDA from the AED, so even if there is a failure in the extension hardware the most valuable equipment is safe. The sensitive parts of the extension hardware are also protected by a thermal resistor and fast anti-parallel Schottky-diodes. The applied shocks are detected by sampling the lowpass-filtered voltage over these diodes, enabling the hardware to also recognize biphasic and oscillating defibrillation pulses, which are used in many newer AEDs. This is possible even for minimal shock energies of 2J with the AED Schiller FRED [Sch03], and is therefore sufficient to initiate a state's change in the scenario, even at this low energy level. The ECG data can be output in 12-bit resolution with a ripple well under the LSB amplitude via two cascaded PWM-outputs from the MSP430.

Figure 3a) shows the PDA with a running PATRES application, the current rhythm is VF. Figure 3b) shows the first prototype of the output hardware. As can be seen, its size is mainly dictated by the size of the resistor and battery, resulting in a size of approximately 10cm x 8cm x 2.5cm. This is compact enough for fitting this module between electrodes and defibrillator.

a) b)

Figure 3: a) PDA with a running PATRES application b) First prototype of the output hardware.

5. Future developments

The next steps in development will be:

- Implementation of entire scenario-programming capabilities under an easily manageable GUI. This will be written in Java, so programming will also be possible on a desktop PC.
- Enhancement of training logging and evaluation capabilities. This includes the automatic marking of events, like detected shocks, as well as the manual tagging of specific events (time of first IV set-up, intubation, drug application etc.).
- Multi-lead ECG output
- Development of a master-multislave network using the capabilities of Bluetooth™ for controlling different output stages from the same single PDA

6. Conclusions

PATRES provides resuscitation trainers with a small, programmable ECG simulator with shock protection for use with any conventional AED. The system's main advantages for trainers compared to other systems are mobility during training and the flexibility in developing custom training scenarios as a new methodic-didactic concept.
The first demonstrations of this system and reactions to an article on this system published in a German journal for paramedics [WS02] were very positive. At the current

state of development, the system is sufficient for use in the training of non-medical staff with AEDs. A first trial in resuscitation training in cooperation with emergency medical care organizations is planned for the near future.
The system also allows for the future implementation of several other uses and applications in the training of cardiovascular emergency cases. To accomplish these tasks, developments in the future may target the integration of the output stage into the training manikins, while the PDA remains mobile to make the training more realistic. In this case, other parameters, like the efficiency of ventilation and cardiac massage, can also be remotely monitored, which is already possible in some manikins. The implementation of the Bluetooth™-inherent networking capabilities will lead to multi-manikin resuscitation training as a new training concept. Multi-lead output and the extension of scenario states with new transition parameters, like medicinal intervention, will lead to a system which can be very valuable in the training of medical professionals. The simulation of other physiological parameters like blood pressure, blood oxygen saturation (SpO_2), breathing, pulse etc. will also target the same group. All these decisions and developments have to be made in close collaboration with end-users and suppliers of resuscitation equipment.

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