Using a Neural Network in a First-Aid Single Point Sensor System to Analyze and Determine Cardiopulmonary Functions of a Casualty in an Emergency

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Abstract

In the paper algorithms are presented that are necessary to analyze cardiovascular and cardiopulmonary parameters which are provided by a first-aid sensor system. The parameters detected at a single point of the patient's neck are combined and interpreted by a neural network.

The algorithms will be integrated into a pocket sized sensor system which thereby provides first aiders with the means to easily and quickly assess the status of the vitality parameters of an unconscious casualty.

The initially detected parameters, i.e. electrocardiogram, mechanical pulse wave and respiration, are analyzed in time and frequency domains and put into correlation. The data is then routed to a neural network.

All the data received will now be reduced to a simple statement of "Cardiopulmonary resuscitation yes or no" which will then be transmitted to the first aider.

1. Introduction

In emergency situations like an accident a first aider has to decide immediately if resuscitation of an unconscious casualty is necessary. At the moment only 14% of the first aiders reanimate a person who needs reanimation [1]. This is because most first aiders are not competent enough in diagnostics and reanimation and thus do not have the heart to do something. Based on the fact that only 45% of the first aiders are able to and do check the pulse correctly [2] only 6% can perform a functional reanimation.

For this reason some research groups try to find ways to detect pulse and respiration by technical means. Some use the Doppler-Method or the pressure caused by respiration and pulse wave on a pressure sensitive sensor. Another method is based on the Pulsoximetry. All these methods have in common that they are able to detect the pulse and respiration non-invasively but apart from a few exceptions pulse and respiration are measured at different points of the body. These methods are not suitable for a first-aid system because they are not easy enough to use for laymen, are not mobile, are rather expensive and have a high energy usage. In addition neither of the systems has signal processing able to analyze the vital parameters.

Our aim is to research a new method for detecting pulse and respiration at one single point of the body. With this we can develop an inexpensive and portable first-aid sensor system to assist laymen in first-aid and especially in the decision for or against reanimation.

The sensor has to be placed on the neck of the casualty (Figure 1) and after a few seconds it starts to display basic information about the status of the casualty's vitality parameters.

Figure 1: Example of the placing and application of the sensor

2. Methods

2.1. Overview

The system is split into three units: The signal acquisition, the signal preprocessing and the signal processing unit (see Figure 2).

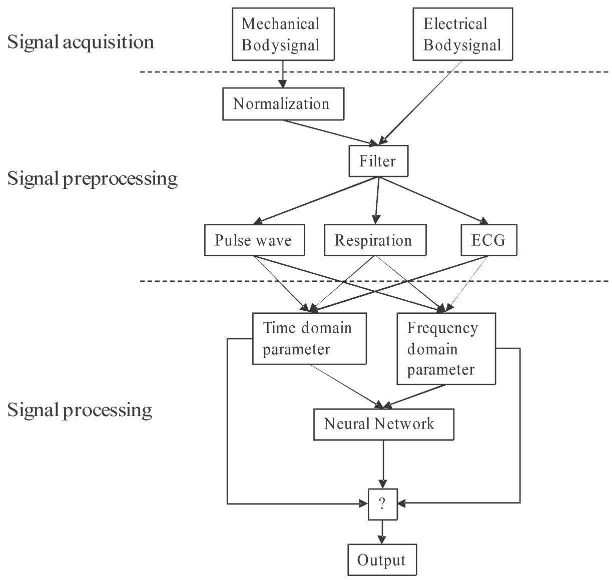

Figure 2: This picture shows the system structure of the first-aid sensor system

2.2. Signal acquisition

The first step in developing such a sensor was to find a way to detect the necessary vital parameters at one single point of the body. Similar to the way one can detect the pulse by hand, the system detects the small mechanical pulse wave of the blood vessel. Unlike the ECG-based technique, this can guarantee that there is a blood ejection from the heart to essential organs like the brain. For respiration detection the system uses effects caused by breathing motion. The best place to detect both is the neck (Figure 3). We were able to measure these small changes in and on the body tissue by using a nonlinear oscillating circuit.

Figure 3: Sensor test on a male patient during a surgery at the Heidelberg hospital

However, since the changes in the tissue surface caused by pulse beat and respiration are very small, a new nonlinear oscillator has been developed. With its help it is possible to measure changes in submillimeter range. Because of this high sensitivity even little muscle contractions will be detected by the sensor. As some of these minor contractions do belong to neither pulse nor respiration they have to be eliminated. It is necessary to filter and process the signal to eliminate these artifacts. An example for the measured signal is shown in Fig. 4. For more technical information please refer to [3].

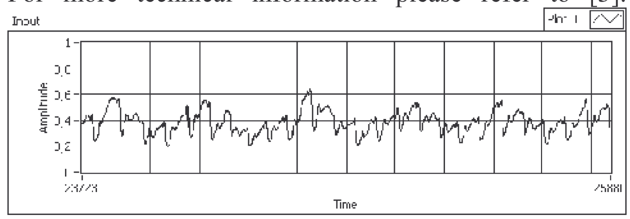

Figure 4: Signal measured by the sensor.

At the moment the sensor delivers a good signal in 94% (Figure 5) of the cases - depending on the location at the neck where the sensor is applied - which is sufficient for further signal processing. In the remaining 6% the signals are not good enough for a safe decision for or against reanimation.

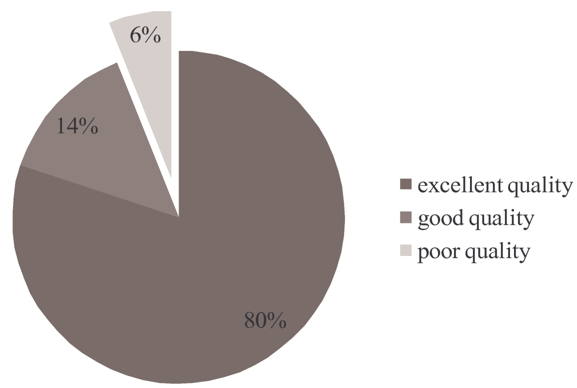

Figure 5: Raw signal quality of pulse and respiration depend on the placing of the sensor on the body

At the moment the electrical body signal (ECG) is used primarily to train the neural net and to validate the data in the laboratory. In future the ECG will be measured at the same place on the neck.

2.3. Signal preprocessing

Before analysing the signal, the mechanical raw signal in Fig. 4 has to be preprocessed.

The first step is a normalization of the raw signal to achieve consistent signals independent from different persons and positions of the sensor (Figure 6).

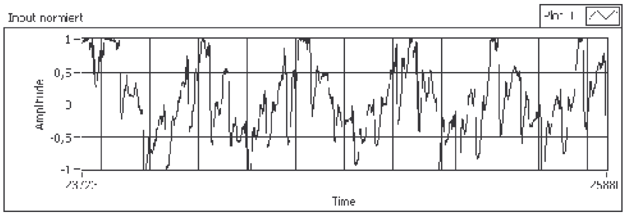

Figure 6: Normalized raw signal

A high- and lowpassfilter splits the mixed signal into respiration (Fig. 7) and pulse wave (Fig. 8). This is the precondition for further time domain analyses.

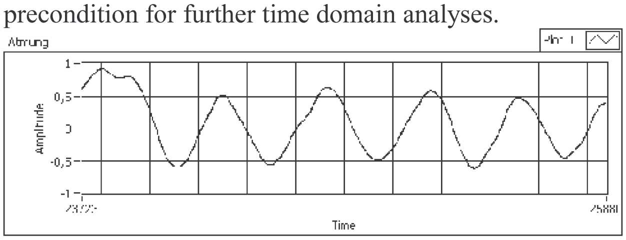

Figure 7: Respiration wave extracted from the raw signal

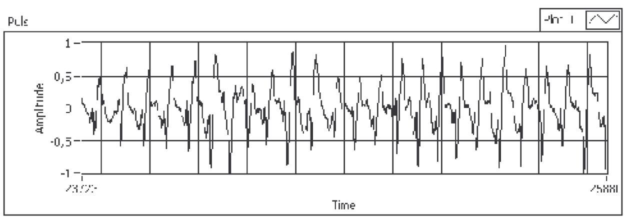

Figure 8: Pulse wave extracted from the raw signal

From these signals we can extract the amplitude of each pulse wave and respiration cycle. This is the first output of the signal preprocessing. Both signals will furthermore be analyzed in time domains regarding their time between two successive maxima. These are the second and third time parameters.

To obtain parameters in the frequency domain a Fast Fourier Transformation (FFT) of the the raw signal will be computed. The two maxima of the FFT show the frequency of the pulse wave and respiration. In extreme cases the respiration frequency can be higher than the pulse frequency. Due to this there are four possible frequency bands (Fig.9):

-the whole frequency band from the lowest possible frequency of the respiration to the highest possible frequency of the pulse (WF)

-the lower frequency band of respiration from the lowest possible frequency of the respiration to the lowest possible frequency of the pulse (LF),

-the upper frequency band of pulse from the highest possible frequency of the respiration to the highest possible frequency of the pulse (HF)

-and the overlapping band from the lowest possible frequency of the pulse to the highest possible frequency of the respiration (MF).

By calculating relations between the different amplitudes, the frequency parts with high intensity can be discerned. Normally there will be only two frequency parts with high intensity representing pulse and respiration.

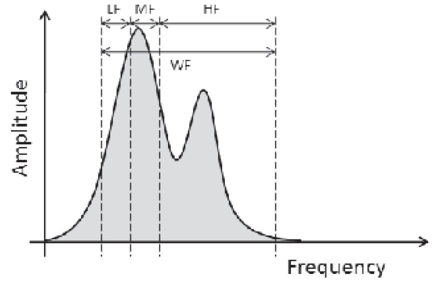

Figure 9: Spectrum of the filtered signal with four frequency bands.

If there are more than two such frequency parts, there has to be a measuring error. If no error is detected, the frequency parts defined above can be analyzed further.

Finally an ECG-Signal will be used as a sixth parameter for the signal processing.

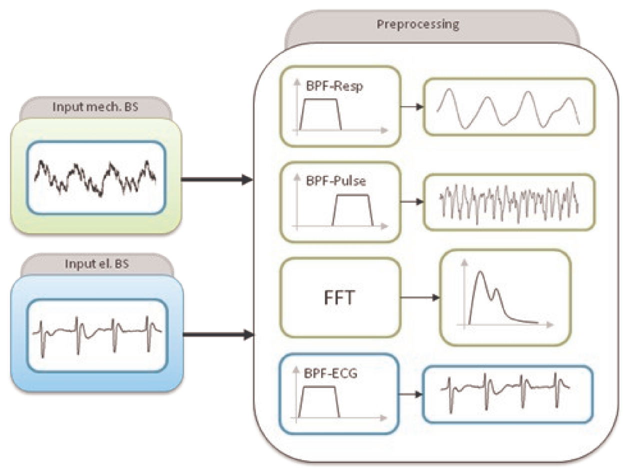

Figure 10: Overview on the signal preprocessing and the different inputs

2.4. Signal processing

In the signal processing unit the preprocessed signals are used as input for the neural network. Considering that the first-aid system in its original version already uses the mechanical pulse wave and respiration, the ECG is a redundant signal. For now the ECG will only be used for tests and to train the net.

Figure 11 shows a block diagram of the signal processing. At the moment only a single layer neural network (Perzeptron) is used for the decision for or against the reanimation.

The output of the neural net is compared with the adaptive threshold of the raw signal. This guarantees that very small signals of pulse wave and respiration are not detected as "Reanimation not necessary". This is necessary because these signals do not necessarily mean that there is air filling the lungs or an adequate blood circulation in the brain.

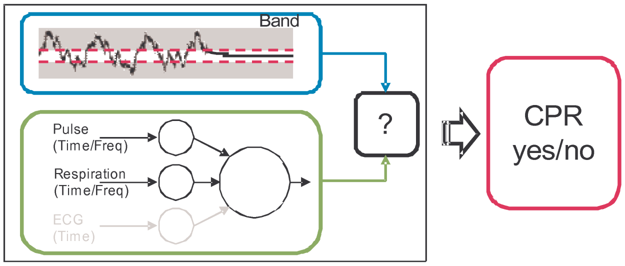

Figure 11: Overview of the signal processing

3. Results

A simple monitoring program of the Sensor used for debugging is shown in Figure 12.

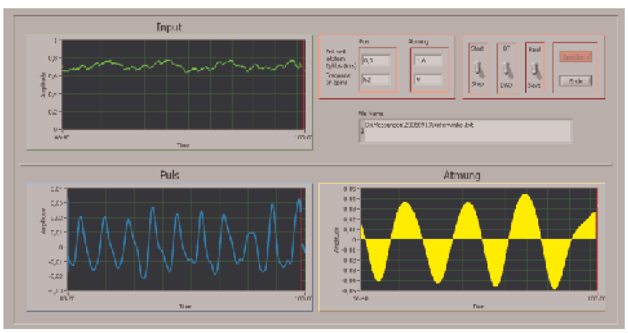

Figure 12: First-aid system test program user interface

The developed algorithms have been tested with several signals recorded by the sensor. Since this is a new approach to respiration and pulse wave detection, no standard datasets are available. Therefore the test dataset and training dataset have been gathered from patients of the Heidelberg University Hospital in different situations. For example data recorded during the implantation of a cardioverter defibrillator can be used as dataset for "Reanimation necessary". To test the defibrillator a cardiac arrest will be induced which in turn causes a stop of the pulse.

For the training and test dataset we recorded about 1000 ten second segments of "Reanimation not necessary" and about 150 ten second segments of "Reanimation necessary".

The results of the algorithms are shown in Table 1.

		Test dataset		S
		Reanimation not necessary	Reanimation necessary	
First-Aid System	Reanimation not necessary	525	16	541
	Reanimation necessary	38	64	102
S		563	80	
Sensitivity		93,3%		
Specificity			80%	

Table 1: Results of algorithms

4. Discussion and conclusions

It seems to be possible to identify persons who have to be reanimated by technical means. We developed a first-aid system including hard- and software of the size of a walnut. The software uses different algorithms to analyze pulse and respiration to support the decision for or against reanimation.

In the next step we will try to improve the neural network to achieve a better sensitivity and specificity especially in situations with a lot of motion artifacts.

Furthermore it is important to test the system under heavy environmental conditions. Therefore a physician will test the system in an ambulance vehicle and in real emergency situations on the street.

References

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