ANALYSIS ALGORITHMS FOR A FIRST-AID SENSOR

Detecting Vitality Parameters such as Pulse and Respiration

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Abstract: In this paper the software algorithms necessary to analyze the signal provided by a first-aid sensor system that detects pulse and respiration at a single point are described. In an opinion poll four of five inexperienced first responders were interested in using this kind of system as support in emergency situations. Especially the intelligent detection of respiration is hardly popular today and in most cases only possible offline. The software also controls several visual indicators that assist the first aider in quickly determining the state of the patient.

1 INTRODUCTION

In emergency situations like an accident a first aider has to decide immediately if resuscitation of the victims needs to be initiated. The know-how of many first aiders is not sufficient or their uncertainty too great to be able to make this often vitally important decision quickly (Sefrin, 2006). Our aim is to develop a cheap and portable sensor system that is easy and fast to use to support the first-aider with their vital decision. It detects if pulse and respiration of the victim work normally and provides the first aider with a visual aid. The sensor has to be placed on the neck of the victim and after a few seconds it starts to display information about pulse and respiration.

2 SIGNAL PROCESSING

2.1 Medical Concept

It is our aim to develop a sensor which measures not only the pulse but also the frequency of respiration, that is why the detection of electrical body signals e.g. like an ECG is not sufficient. One solution is to measure mechanical changes of the tissue surface which are caused by both pulse beat and respiration. As possible measuring point for the sensor a point near the clavicle is estimated to deliver the best results because that point is close to both the subclavian artery and the trachea. This point is shown in Fig. 1.

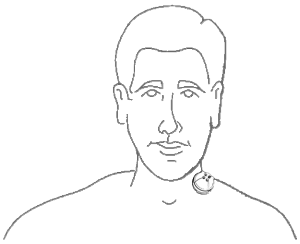

Figure 1: Possible measuring point for the sensor.

2.2 Signal Acquisition

The measuring of changes in the tissue surface is mainly done by detecting changes in distance between the sensor and the tissue surface. Normally the measuring of distances can be achieved by using an LC oscillator. Due to capacitive coupling the resonance frequency of the oscillator changes if the

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distance to any organic object in- or decreases. This change in resonance frequency is reflected in a change of voltage. This principle is used in homes in the form of touchless switches. However, since the changes in the tissue surface caused by pulse beat and respiration are very small, the use of classical LC oscillators is - apart from a few exceptions - not possible. Therefore 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. 2. For more technical information please refer to (Jaeger, 2007).

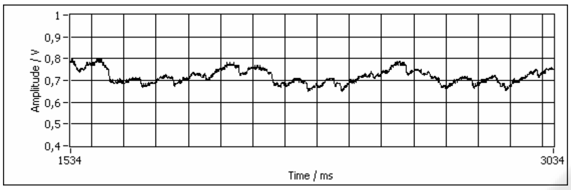

Figure 2: Signal measured by the sensor.

2.3 Algorithms

First the signal is band-filtered with hard coded cut-off frequencies covering the whole spectrum of possible pulse and respiration frequencies. In the next step a low resolution FFT of this filtered signal is performed. In extreme cases the respiration frequency can be higher than the pulse frequency. Due to this there are four possible frequency bands (Fig.3):

- 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.

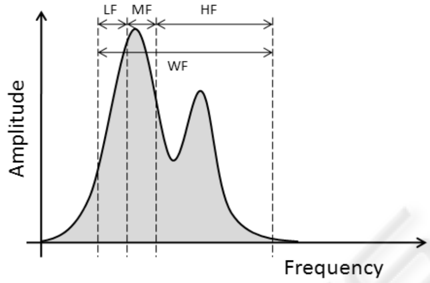

Figure 3: Spectrum of the filtered signal with four frequency bands.

If there are more than two such frequency parts, there has to be a measurement error. If no error is detected the frequency parts defined above can be analyzed further. If there is a frequency part of high intensity in the lower frequency band of respiration, there may be only one such frequency part in the overlapping band - the one of the pulse. If such a frequency part is additionally detected in the upper frequency band of the pulse there cannot be any in the overlapping band. As soon as these conditions are met, the frequencies for pulse and respiration are approximately determined. With the detected frequencies it is possible to define narrow cut-off frequencies for pulse and respiration. With these cut-off frequencies the input signal is filtered again, once for pulse and once for respiration.

After this step there are two rather clear signals which are relatively free of errors. With these filtered signals it is possible to determine more exact frequencies for pulse and respiration. Therefore the filtering is designed to adapt which means that the cut-off frequencies of the fine filters are always readjusted using the frequencies determined by the fine filtered signals. Additionally the approximated frequencies of pulse and respiration gained from the roughly filtered input signal are used to validate the adjustment of the cut-off frequencies for the fine filters. The determination of the frequency of the fine filtered signal works as follows: On the one hand zero-crossings are counted using a hysteresis, on the other hand a high resolution FFT for the filtered signals is processed. Both results undergo a plausibility check.

The frequency determination by counting zero-crossings is done by using hysteresis. A zero-crossing is only interpreted as such if the signal does not only drop below a lower hysteresis border but then also rises over an upper hysteresis border. The point in time in which the signal rises over the upper hysteresis border is used as zero-crossing. The time difference between two such points can be interpreted as the periodic time of the signal. The reciprocal of this periodic time is the frequency of the signal. To get a more stable frequency value the last two periodic times determined in this way are averaged. If the signal does not pass a hysteresis border for a certain period of time its quality is assumed to be insufficient and the frequency value will be set to zero.

When the frequency is determined by using a high resolution FFT the frequency part with the highest amplitude is used as result. To get a more reliable value the algorithm averages out the last five determined frequency values.

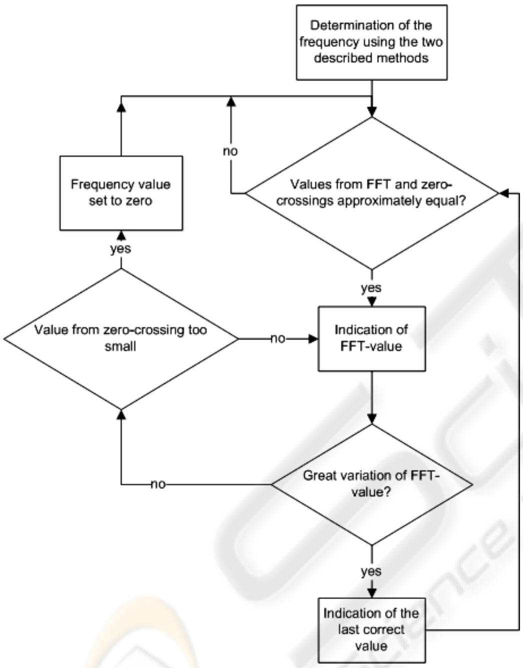

Figure 4: Logical organization of the plausibility check.

To eliminate remaining errors a plausibility check is done using the determined frequency values by counting zero-crossings and FFT. Fig. 4 shows the logical organization of the plausibility check.

As soon as both methods - counting zero-crossings and FFT - calculate approximately the same frequency value the signal is assumed to be free of errors and the value calculated by FFT will be indicated as final result. If this value deviates too much from the previous shown result an error will be assumed. In this case the last correct value prior to the error is indicated until both methods once again calculate an approximately equal value. If the value determined by counting zero-crossings drops below a predetermined border, the signal is assumed to be too weak and the final frequency value will be set to zero.

Fig. 5 shows the chronological sequence of possible results of the two methods counting zero-crossings and FFT and the corresponding result of the plausibility check (frequency line in Fig. 5).

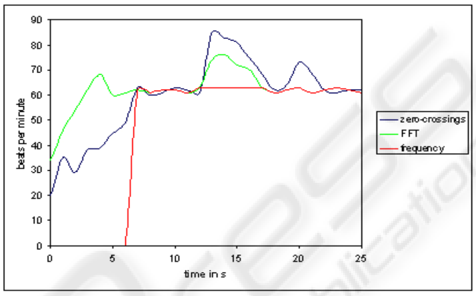

Figure 5: Possible chronological result of the plausibility check.

2.4 Visualization

The sensor uses LEDs to indicate the state of a patient. For both pulse and respiration there is a LED showing if the respective function works normally. If either pulse or respiration are abnormal, it will be shown by an additional LED. A fourth LED indicates that the sensor system is working correctly to avoid any delay due to unrecognized malfunctions. The sensor with its LEDs is shown in Fig. 6.

Figure 6: The Sensor with the four LEDs.

If the LEDs indicate that pulse and/or respiration does not work normally and the patient does not show any reactions to external stimulation the first aider has to initiate cardiopulmonary resuscitation (CPR).

3 APPLICATION

The following diagram (Fig. 7) shows the sequence from the arrival of a first aider at an accident up to the corresponding action he has to take.

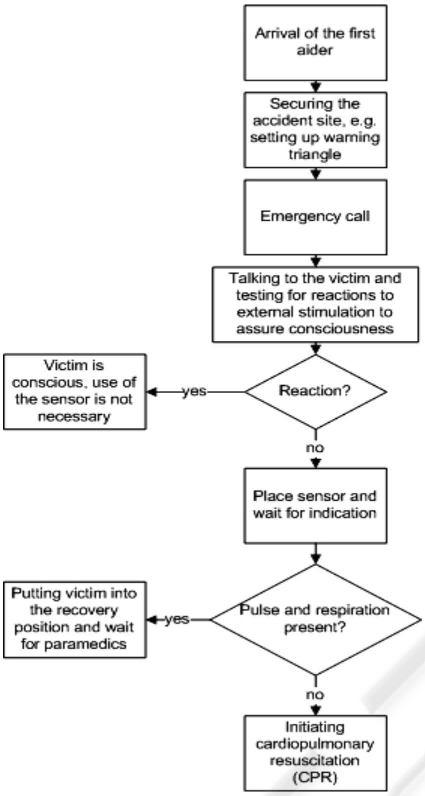

Figure 7: First aider mode of operation.

4 RESULTS

The developed algorithms have been tested with several signals recorded by the sensor. The time it took the software to detect each the pulse and the respiration signals has been put in relation to the overall time of the measurement. The results are shown in Table 1. The sensor is able to detect pulse in 91.15% and respiration in 81.15% of the time the sensor is active. The timeframe during which pulse and respiration are not detected is mostly at the beginning of the measurement because at least one or two cycles are necessary to calculate useful values. The lower percentage for respiration detection can be explained with the lower breathing frequency due to which the initial cycles take longer to complete.

Table 1: Test cases for pulse and respiration.

	Signal length in s	Pulse detected in %	Respiration detected in %
75.txt	132,92	92,33	87,71
84.txt	191,55	97,49	92,69
87.txt	97,90	95,86	85,41
90.txt	80,63	94,51	78,69
137.txt	76,13	96,69	79,64
190.txt	119,59	97,12	71,99
carotis.txt	29,22	83,06	57,56
kieferwinkel.txt	169,61	97,70	91,16
sternoclaido.txt	199,36	83,74	82,68
subclavia.txt	74,99	73,00	84,00

5 DISCUSSION

The results shown in Table 1 are not satisfying because they were not verified by comparing them to actual pulse and respiration data detected by other means. In addition the sensor has to be tested in extreme situations for instance on board of rescue helicopters and ambulances again while comparing the sensor data to actual pulse and respiration data. According to these test results - like possible deviations of the sensor detected data from the actual pulse and respiration - the algorithms will have to be improved. The main task in the future will be to find ways to correct inaccuracies caused by small movements. This could be done for example by integrating a neural fuzzy system into the software that can use additional criteria to ascertain that the calculated values are correct.

Another possibility is to include an acceleration sensor in the system that is able to detect certain movements and to correct the data accordingly.

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