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First-aid sensor system: New methods for single-point detection and analysis of vital parameters such as pulse and respiration

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Abstract— **The paper describes a first aid medical sensor system that is able to detect pulse and respiration. According to an opinion poll 79% of unexperienced first aiders were looking forward to use a system that supports them in first aid situations. Such a device has to be reliable and available in everyday use (e.g. as a keychain or in a first-aid kit). Therefore we investigated a single point sensor that is able to detect both respiration and blood flow at the same point of the body, for instance on the neck. Compared to ECG-derived methods absent pulse due to pulseless electrical activity (PEA) will be recognized as such. Tests have shown that the sensor can also be used to detect deglutition and other body motion sequences.**

I. Introduction

Cardiovascular diseases are a common cause of death in industrialized countries. In Germany almost 44% of all deaths are caused by failures in the cardiovascular system. Ten percent die because a sudden cardiac death causes an arrest of the cardiovascular system. There are many different reasons responsible for this critical state. For example cardiac infarction, injuries caused by accidents or an electric shock can cause a cardiac arrest, unconsciousness and stop autonomous respiration. Therefore it is important for patients to get immediate help, like cardiopulmonary resuscitation (CPR). With every minute that passes without medical action being taken, the probability of being able to save the patients life decreases by ten percent [1]. After 10 minutes there is normally no chance of resuscitation being successful.

To prevent this, it is important to be trained in CPR. It is essential to know how to check the awareness, the pulse and breathing of a casualty and how to perform CPR. Problems arise when people who have forgotten the contents of their first-aid course are confronted with a situation that makes first aid and even immediate CPR necessary.

Changes in the resuscitation guidelines over time are another problem. In 2005 the European Resuscitation Council Guidelines for Resuscitation [2] were changed. Now the first aider is supposed to speak to the victim. If the victim is unresponsive, the first aider only has to check the respiration. Before 2005 an additional pulse check at the carotid artery had to be performed before starting CPR. The reason for omitting the pulse check is the missing willingness and/or incompetence observed in first aiders [3].

Many people who are related to rescue services dislike this decision. In an opinion poll of the University of Karlsruhe with over 1000 participants [4] 82 percent said that pulse is an important parameter and that they will continue to include checking it in their initial examination. (Fig.1).

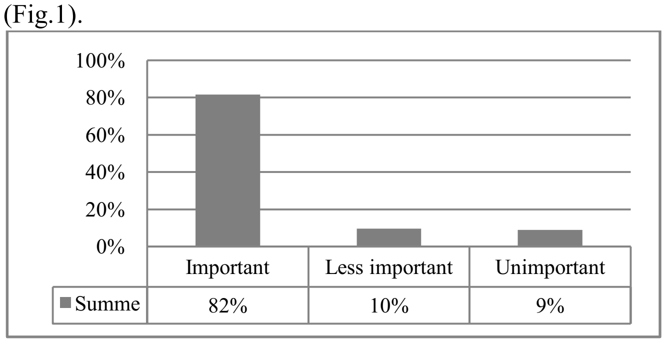

Fig. 1: People's opinion on the importance of measuring pulse in first aid

The aim of this work was to find a system that assists first aiders. Our intention was to research a “first-aid sensor” able to detect pulse activity and respiration signals. For this it was necessary to develop a reliable and low-priced medical sensor system that is always available.

In the following we will describe the operation of a first-aid sensor system and the acquisition of body signals like breathing, mechanical pulse wave or muscle action.

II. First-Aid Medical device

A. Signal acquisition

The basic step in this work was to find a way to acquire all the vital signs like respiration and pulse punctual at the same place on the skin. Similar to using the hand to check the pulse by feeling the carotid artery, the system has to be able to detect the 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. As for respiration there is neither need to

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differentiate between abdominal or breast respiration nor between breathing through nose or mouth. Only the existence of adequate air flow is important for a first-aid sensor system. So we need to detect effects caused by breathing motions. In Fig. 2 the principal methods with examples are shown

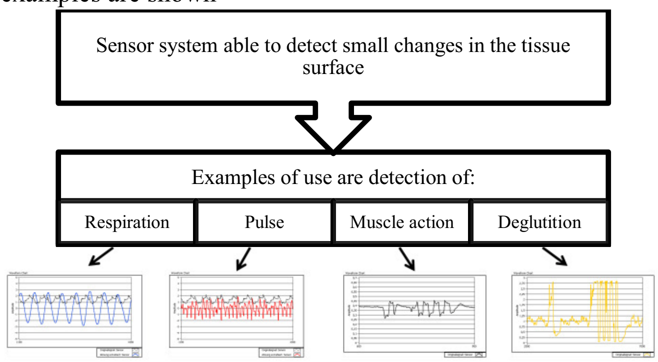

Fig. 2: Principal methods and examples of use

The principle is to detect small changes in the surface of the skin. This does not include changes like skin abscesses or lesions, but merely effects caused by motions such as breathing or local changes of the skin surface caused for instance by the pulse wave, blinking, deglutition and others.

To measure these effects we use an oscillating circuit. With an LC-oscillating circuit it is possible to acquire electric signals caused by changes of the distance between the circuit sensor and in our case the skin [5]. The principle is based on detuning the resonance circuit by capacitive, inductive and absorbative effects. Every approach of a material to the circuit evokes these effects. In home building it is used to realize touchless switches.

The classic system consists of components shown in Fig. 3. A frequency synthesizer generates an alternating current with a frequency ranging from one to ten megahertz. The oscillatory circuit is based on an inductance and a capacitance with a resonance frequency close to the frequency of the synthesizer. To decouple an electromagnetic near field to detect changes in capacitance or dampening an antenna is necessary. To convert the distance into readable values an analysis unit based on a microcontroller or analog circuits has to be implemented.

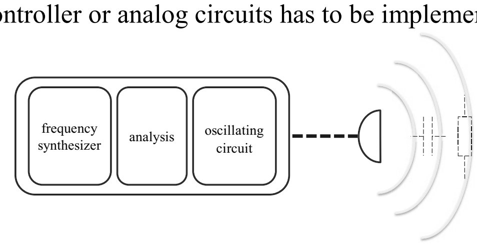

Fig. 3: Block diagram of a system that is able to detect changes in distance

The resonance curve of a linear LC-oscillatory circuit depends on the values of capacitor and inductor and is shown in Fig. 4. The formula used to calculate the resonance frequency is

$$v_0 = \frac{1}{2\pi\sqrt{LC}}$$

The LC-circuit will be stimulated by the frequency synthesizer next to the resonance frequency with f_1. This causes the circuit to oscillate with a lower voltage amplitute U_1. Changes in capacitance alter the resonance frequency and cause higher or lower voltage. In Fig. 4 a changes of Δf causes a voltage rise of ΔU.

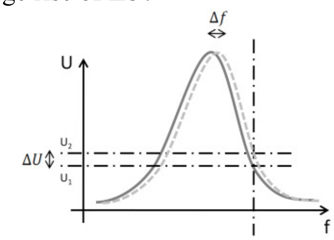

Fig. 4: Resonance curve of a linear LC-circuit. Y-Axis: a.c. voltage

Bringing the antenna close to a conducting material like metal or body tissue also generates eddy currents. This ohmic drop does not alter the resonance frequency but dampens the circuit and in turn reduces the whole amplitude. This effect is not as important as capacitance effects but it should not be neglected.

The system described before is sufficient to measure wide changes in distance e.g. for industrial purposes like sensors for fluid levels or counting of goods. It is not sensitive enough for medical applications such as detection of pulse and respiration since the signal quality and accuracy is not sufficient to detect small motions in the submillimeter range.

For this reason we researched a new nonlinear oscillatory circuit [6]. With this we can adjust to any needed sensitivity by making the resonance curve steeper on the right side. In Fig. 5 the new sensor system using the nonlinear oscillation circuit is shown.

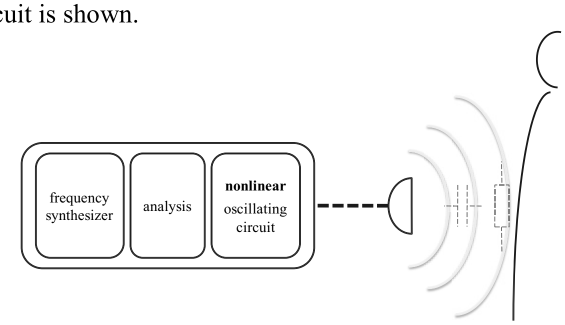

Fig. 5: Block diagram of the new system that uses a nonlinear oscillating circuit

The equation for this system is formed using a linear capacitor, a linear inductance, and a nonlinear varactor diode as follows:

$$\frac{\partial^2 q}{\partial t^2} + \frac{1}{L \cdot C} q + \frac{u_v}{L} = \frac{k \cdot \hat{U}_e}{L} \cdot \cos(\omega t)$$

The characteristic curve for small changes is:

$$C_v(u) = \frac{C_0}{\left(1 - \frac{u}{U_d}\right)^m}$$

The corresponding resonance curve of the nonlinear system is shown in Fig. 6. Small changes in capacitance cause changes of resonance frequency in linear resonance curves as in nonlinear resonance curves. Therefore the curve shifts to a higher or lower frequency. Even small shifts cause big d.c. voltage variations due to the steep right side of the curve. These d.c. voltage variations are proportional to respiration and pulse wave.

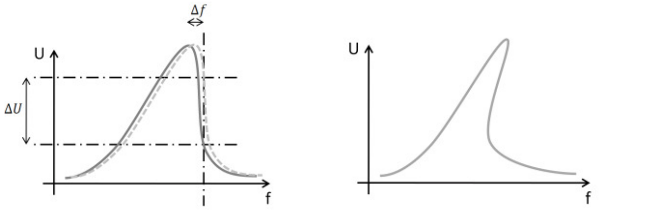

Fig. 6: Resonance curve of the new nonlinear LC-circuit; left: very steep flank; right: overhanging curve; Y-Axis: d.c. voltage

In this example (Fig. 6) the same Δf in compared to Fig. 4 results in a significantly larger increase in voltage. If ΔU is not sufficient, the sensitivity can be increased until the resonance curve is hanging over (shown on the right side of Fig. 6)

B. Functionality in medical application

The presented system was designed primarily for use by first aiders. The main requirements for it are to be ready to use in short time and reliable in detecting pulse and respiration. To achieve this it is necessary to find out what kind of detectable changes are caused by pulse and respiration. The most important medical aim is to ensure that the brain is being supplied with oxygen. In Fig. 7 the necessary conditions are shown:

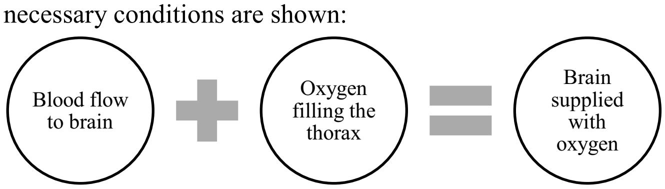

Fig. 7: Essential life-preserving functions

First of all there has to be a blood flow in the carotid artery on the left and right side of the neck. Secondly the blood has to be enriched with oxygen, which requires adequate respiration.

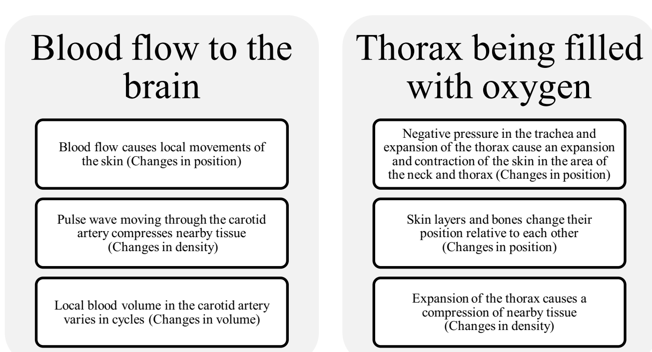

Fig. 8: Measurable side-effects caused by pulse and respiration

Both effects, the "blood flow to the brain" and "filling the thorax with oxygen", create further effects (shown in Fig. 8). Pulse wave and respiration cause changes in the tissue surface. The idea is to detect and interpret those effects. There are changes in volume, changes in density and changes in position caused by pulse and respiration. Every effect causes a modification of the equivalent circuit diagram, namely a shift or a dampening of the nonlinear resonance curve (Fig. 9 shows those effects).

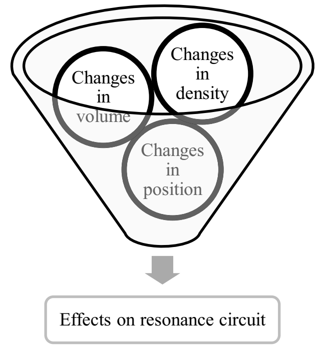

Fig. 9: Effects influencing the resonance circuit

C. Human-machine interface

The sensor system is based on an isolated ECG-Pad and is to be placed close to the carotid artery acting as an interface between skin and electronics. The tolerance zone is big because the effects used to detect the pulse are not limited to the area over the blood vessel. Detection of respiration is unproblematic over a great range at the neck because the effects of negative pressure in the trachea are evenly spread.

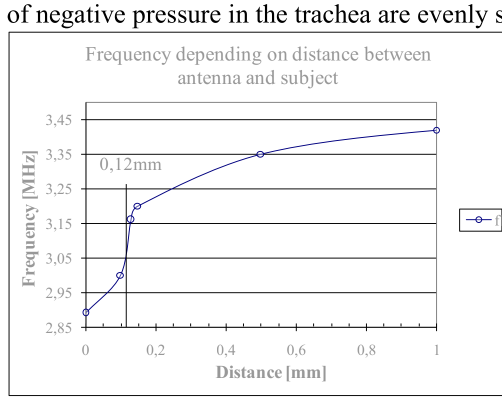

Fig. 10: Optimal distance between skin and antenna for obtaining maximum signal from sensor

The optimal distance between antenna and skin surface can be seen in Fig. 10. At a distance of 0,12mm there is a maximum frequency shift in the nonlinear oscillating circuit and so the best distance for obtaining maximum signal from sensor.

III. Materials and Methods

The sensor system is integrated in a small box with an external power supply and a data interface connected to a computer via an analog-digital converter. A disposable isolated electrode establishes the contact to the skin (e.g. neck, breast or abdomen). This electrode consists of a thin metal plate and a self-adhesive carrier material. Depending on the field of application (see in Fig. 11) different types of electrodes can be used. To detect very small effects – e.g. pulse, respiration or blinking – a very flexible pad has to be used. For bigger changes in the skin surface caused by muscle-motion or deglutition that are easier to detect it is necessary to dampen the motion effects. The isolation between antenna and skin provides the necessary distance of 0,12mm and protects the system from a defibrillation shock of up to 6 kV.

To see the real time data from the sensor the raw data is imported into LabView via an analog-digital interface card. For the detection of pulse wave and respiration a simple high- and lowpass is sufficient to separate the mixed body signals.

The system is currently being tested at the Heidelberg University Hospital for use in a first-aid sensor system. The sensor has also been tested in standard surgery situations as seen in Fig. 11 on the left side.

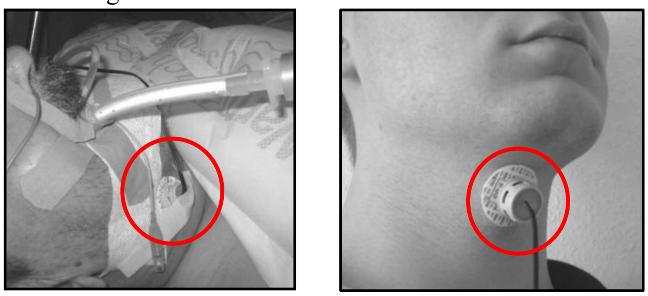

Fig. 11: Left - Sensor test on a male patient during a surgery at the Heidelberg hospital; Right - Test to detect movement of the larynx during deglutition

Beside tests on detecting respiration and pulse there are trials being done by the University of Berlin using this sensor to detect movement of the larynx caused by deglutition.

IV. Results and Discussion

First test results on using the system to detect respiration and pulse are shown in Fig. 12. The black line in Fig. 12 shows the raw signal from the sensor measured at the position shown in Fig. 11. In spite of the adipose neck of the patient the signal is satisfactory. The high frequency line (red line) represents the pulse wave that has been extracted from of the raw signal. The low frequency line (blue line) corresponds to breathing respectively tracheal respiration.

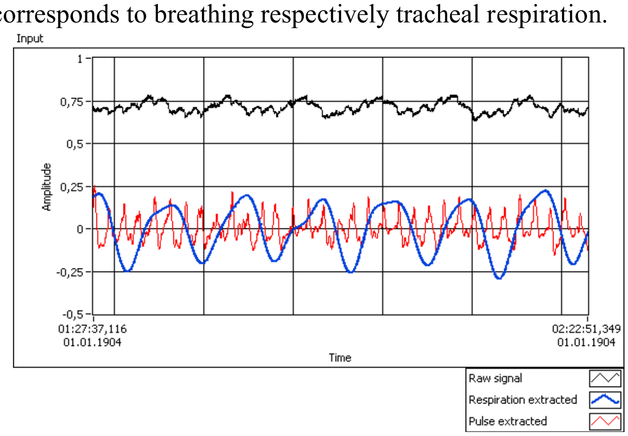

Fig. 12: Using the sensor to detect pulse and respiration

An extensive clinical validation trial of the system is in progress. The primary focus of the clinical tests will be the reliability of the system and its suitability for daily use. Therefore the system will be tested in different situations including situations in which the cardiovascular system fails. This can occur during surgery for example when a cardioverter-defibrillator implantation is being performed. To test the defibrillator a cardiac arrest will be induced which in turn causes a stop of the pulse. Additionally the performance the system will be tested by a medical student in emergency situations. He will place the system on the neck while the emergency physician reanimates the patient.

An example of a short test series that detects the movement of the larynx is shown in Fig. 13. The sensor is placed on the neck according to the right side of Fig. 11 on the right side. During deglutition the respiration stops and the signal peaks.

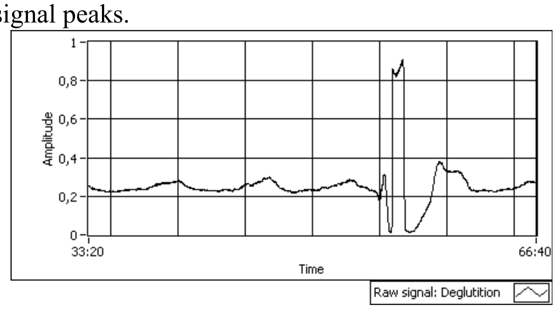

Fig. 13: Sensor signal showing the peak during deglutition

In this paper we described the analog signal acquisition. To be suitable for first-aid kits the system has to provide some additional functions. It is not enough to display the pulse wave and respiration curve because people who have no relation to medicine cannot interpret the data. Therefore the system has to be able to analyze the data automatically and it has to provide the first aider with an audio- or visual hint on what to do. There could be an LED on the sensor that starts blinking if there are no vital signs being detected. This would tell the first aider that he has to perform CPR. The complex algorithms necessary to interpret the vital signs and to convert them into a clear indication for the first aider are in progress.

References

[1] J. Schöchlin. (2003, May). Technische und organisatorische Maßnahmen jenseits der AED: Was brauchen wir noch? [Online]. Available: http://www.fruehdefi-ka.de/

[2] A.J. Handley, R. Koster, K. Monsieurs, L. Bossaert, “European Resuscitation Council Guidelines for Resuscitation 2005. Section 2. Adult basic life support and use of automated external defibrillators”, *Resuscitation*, pp. 7-23, 2005

[3] P. Sefrin. (2006, April). Bei der Reanimation gilt ab sofort: Zuerst 30mal das Herz massieren und dann zweimal beatmen. [Online]. Available: http://www.aerztezeitung.de/docs/2006/04/10/066a0203.asp?cat=/medizin/herzkreislauf

[4] M. Jaeger, „Expertenmeinung zum Umgang mit bewusstlosen Personen im Hilfeleistungs- / Rettungseinsatz. Institut für Biomedizinische Technik“, *Universitaet Karlsruhe*, 2006

[5] Ifm electronic. (2006). Kapazitive und Füllstandssensoren – Schulungsunterlagen. [Online]. Available: http://www.ifm-electronic.com/ifmweb/ifmbigob.nsf/reffiles/S160d/$file/S160d.pdf

[6] M. Jaeger, R. Jaeger, A. Bolz, „Respirationsdetektion mittels Mikroklebesensoren“, *Gemeinsame Jahrestagung der Deutschen, Österreichischen und Schweizerischen Gesellschaft für Biomedizinische Technik*, 2006