Parallel Signal Acquisition by an Embedded System for Monitoring and Analysing Multimodal Signals of Aliveness and Non-aliveness of Biological Objects

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***Abstract*—The multimodal sensor system that is presented in this paper has been developed to measure and analyze typical information of biological objects. The heart of the system consists of a field of light emitting diodes combined with photodiodes. The light emitting diodes are characterized by several peak wavelengths in the visible and in the near infrared range. Primarily, these optoelectronic components have the function to measure the heart rate and the oxygen saturation of a person's finger. Furthermore, the special arrangement of the optoelectronic components is implemented to measure the remission of diffuse reflectance from the depth of a few millimeters of the measurement object. A hardware fusion with ancillary sensors to measure the temperature, the bio-impedance and the humidity of the measurement object is realized, too. All sensor signals are measured with a high sample rate in the presented system.**

Keywords-Multimodal sensor system; hardware fusion; additional tool for biometric application.

I. INTRODUCTION

With smart devices, watches and fitness tracker, there is a variety of utensils for the acquisition of individual data of personal health condition. Most devices use only a limited number of sensors and estimate from these data the actual variables of interest (e.g., fitness activity by pulse and Global Positioning System (GPS) coordinates; quality of sleep by the heart frequency). Often these devices only communicate online with a server, or send the resulting final value via an App to a mobile phone. Thereby, it is not possible to get a detailed insight of the original acquired data, not to mention a deeper and comprehensive analysis of these data.

In this work, we present the development of a bio-monitoring system, which makes it possible to make statements about the heart rate, the variability of the heart rate and the bio impedance, the ElectroDermal Activity (EDA) and other bio and vital parameters. Even other, non-human, biological objects, for example food, can be analyzed by this combined sensor system, so a rating about the aging, the decomposition level and a consumption recommendation could be created. Here again, other approaches use only optical analysis methods.

In Section II, we show the concept of the measurement system in principle and describe the details of the built-in hardware like the used sensors and other components of the embedded system. In Section III, we explain some features of the measurement system and sketch possible areas of application. In the end, in Section IV, we summarise the central points and give an outlook for further development and the future use.

II. SYSTEM DEVELOPMENT

A. Sytem concept

We developed a multifunctional measurement device for monitoring different parameters of biological objects. This device is used for acquisition, digital storage and for time-series visualization of the measured parameters.

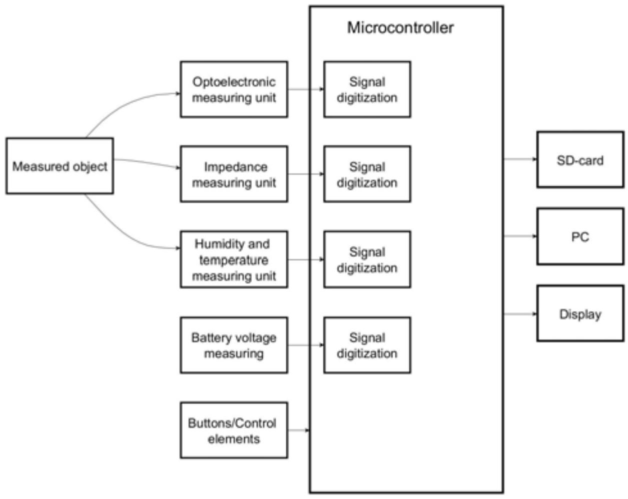

Figure 1. Block diagram of the device with the communication channels from the sensors/elements, via the microcontroller through to the data output/storage.

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We designed the device as an embedded system (Figure 1). It consists of parallel channels to measure the remission, the bio-impedance, the humidity and the temperature of objects almost simultaneously.

By using a battery and an Secure Digital Memory Card (SD-card), the device operates as a stand-alone system in most cases. It can also operate as a PC-controlled unit.

B. Details of realising the sensitive hardware

The size of the measurement device should be kept small so the device is still handy (Figure 2). It contains a small chamber to measure the humidity, the temperature and the bio-impedance of a biological object, for instance a living person's finger. Furthermore, there are Light Emitting Diodes (LEDs) and an area of photo diodes on the contact area of this chamber (Figure 3).

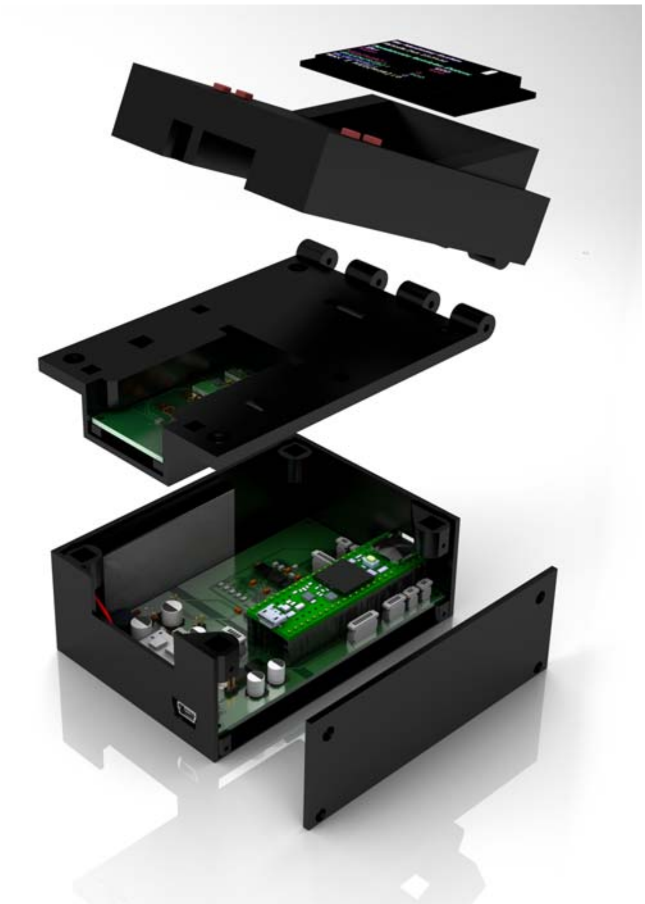

Figure 2. Design of the measurement device, useable as an about fist-sized, stand-alone, mobile monitoring and analysing system. Exploded view showing, top to bottom, the display and control elements, the measurement chamber and the electronic components, microcontroller-board, SD-card slot and USB port.

For some applications, e.g., for liveness detection in biometric applications, it is very important to get all the information of the object from a measurement of a small, spot-sized area [1]-[3]. That is why all sensors of the system are placed relatively close to each other, like illustrated in Figure 3.

The heart of the system is an optical field (upper part of Figure 3.(a)) consisting of three LEDs and five photo diodes. The LEDs are located in the center of this field, whereas the photo diodes are arranged around the center. Therefore, it is possible to detect phenomena of intrinsic absorption of the objects, in the lateral dimension and into the depth of the object [4][5].

To get information of the depth of biological objects, it is important to emit wavelengths of the so-called tissue-optical window in the range of approximately 650 – 950 nm [6][7]. We choose a 660 nm RED-LED (type: SML-LXFM0603SRC) and a 940 nm NIR-LED (type: VSMB1940X01) for this.

Furthermore, we integrated a RGB-LED (type: SMLVN6RGB) in the optical field. Hence, the user of the measurement system gets the possibility to tune an emitting wavelength of the visual light range by the software control of the RGB-LED. Optionally, an UV-LED can be placed instead of this, if it seems to be more advantageous for samples and special objects [8].

To detect the diffuse remission from the biological objects, high-sensitive photo diodes (type: ADPD2211) are used. Each of them has an integrated current-amplifier, so a separate transimpedance amplifier is not necessary.

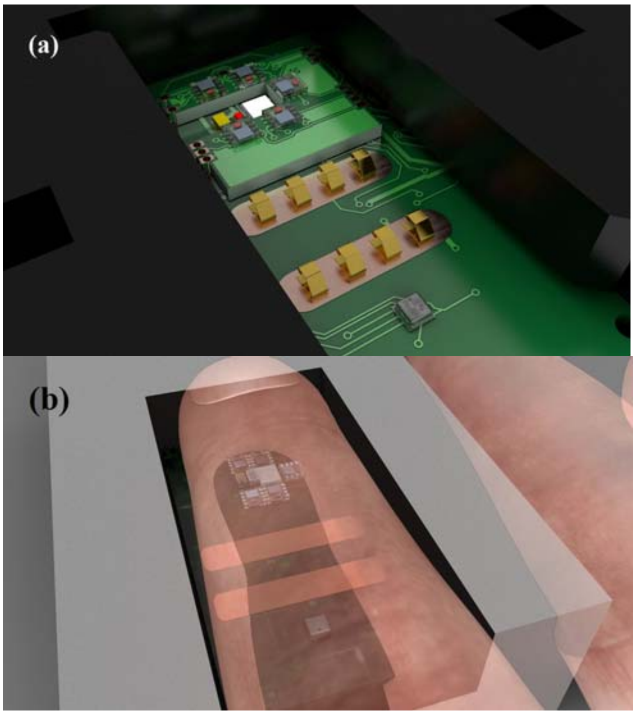

Figure 3. The heart of the measurement device. (a) measurement chamber with the optical field (three LEDs and five photo diodes), two electrodes with superimposed contact springs and a combined sensor for measuring the temperature, pressure and humidity (the grey square). (b) Finger superimposed on the contact area.

Near the optical field, two electrodes in the form of two broad metal strips can be seen (Figure 3.(a)), which are added with superimposed contact springs for a better contact to an applied finger, or sample. These electrodes are there to measure the bio-impedance [5][9]. In dependency of the distance of the electrodes on one hand and in dependency of the stimuli-voltages respective currents on the other hand, it is possible to get electrical impedance information of different depths of the biological measurement object [4][10]. In our case, the realized bio-impedance measurement works by using a constant current source. While injecting a constant current into the skin the system measures the voltage drop and the phase shift in relation to the current. Next, the system calculates the impedance from the measured values.

Finally, you find on the contact area (at the bottom of Figure 3 (b)) a combined sensor (type: BME280) to measure the humidity and the temperature of a presented measurement object (This combined sensor is able to measure the pressure, too. However, we do not use this functionality in our applications).

C. Details of the embedded system hardware

The measurement device, which is about fist-sized, consists of an embedded system hardware. The developed measurement device is based on a 32-bit ARM-processor, the NXP/Freescale MK64FX512VMD12Cortex-M4F processor with 120 MHz, 512 kB flash memory and 192 kB RAM. As microcontroller-board a Teensy 3.5 is used. This microcontroller is compatible to Arduino and its firmware was designed in the Arduino IDE.

The measurement device is equipped with an SD-card unit and is powered by a rechargeable battery. Therefore, this design enables a stand-alone use as a small mobile device.

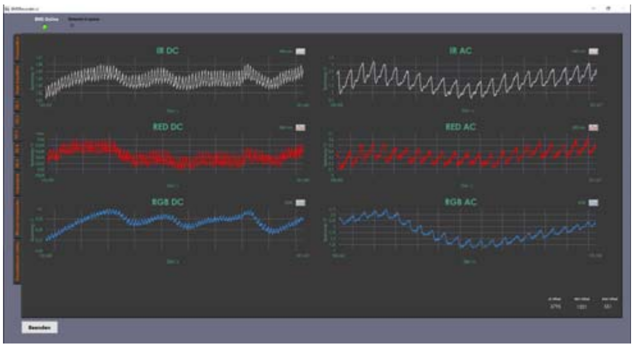

Figure 4. Graphical User Interface (GUI) of the LabVIEW-software-PC monitoring results of exemplary measuring signal courses of the reflections of the different LED wavelengths. Here, three pulse curves are shown. In addition other biological parameters, like, for instance, amplitude and phase shift of the bio impedance measurement can be displayed additionally. Also, the PC control elements are available in this LabVIEW GUI.

An USB port allows the measurement device to communicate to a PC and thereby the data export from the microcontroller to a PC is possible. So, the measurement signals can be visualized and analyzed directly and, at the same time, it is possible to store them as a base for the further development of multimodal analysis routines for various issues.

The PC Software is implemented with LabVIEW and the PC graphical user interface is shown in Figure 4. The signals of the photo diodes are shown for the three different LEDs and the DC- and AC-parts are presented separately.

III. Advantage and Benefit of the Measurement Device

In contrast to conventional pulse oximeters [1][6], which typically output averaged values of the heart rate and the oxygen saturation, our measurement device provides much more information about the status of the probed persons. For instance, the information received includes the time-resolved heart rate (and out of this the heart rate variability is identifiable), changes of the respiratory rate, the temperature and investigation of tonic and phasic EDA (variability of the bio-impedance). In addition, information about the transpiration and the peripheral blood flow through a person's finger pad are also available. Different time regimes can be useful depending on the investigation purpose. Figure 5 shows the results of two different measurement options/variants. The figure shows the heart rate measurement results obtained with two different wavelengths. Through the respective pulse curves, it is possible to calculate the oxygenation of the blood in a noninvasive method [8]. Two alternatives to get the blood oxygenation level are presented as a function of time.

For the first method, shown in Figure 5 (a), one needs the acquisition of multiple, at least five, periods of the heart beat obtained by infrared radiation (940 nm) and save the AC and DC parts. Then one irradiate the tissue with red light (660 nm), again for at least five periods of heart beat and then calculate the oxygenation of the blood [7][8].

In the second method, shown in Figure 5(b), the system is alternating switching on and off the red (660 nm) and infrared (940 nm) LED with a high frequency, for example with 1 kHz, in equally spaced time intervals. By doing this, one can calculate the oxygenation of the blood again (theoretically after two periods of the heart beat) [6]. For both methods of oxygenation level determination, a low-pass filtering of the signals is necessary. Furthermore, the second method has the advantage to reduce the potential negative influence of environmental light/ambient light.

An additional operational scenario for this measurement device is the inspection and evaluation of food, e.g.[11]. Through the multimodal analysis of the measured signals, it is possible to obtain a lot more information about inherent material properties of biological measurement objects. For instance, it is possible to get insights about the freshness, respectively about the age of food. It is commonly known that the aging of meat, fish, cheese, eggs, vegetables and so on, causes generally the drying and colour change of these food products. Both can be measured by our device. In addition, a qualitative evaluation with respect of the composition of processed food products (ingredients, inferior food additives, preservatives, artificial colours and flavourings) can be possible. Through this analysis, a

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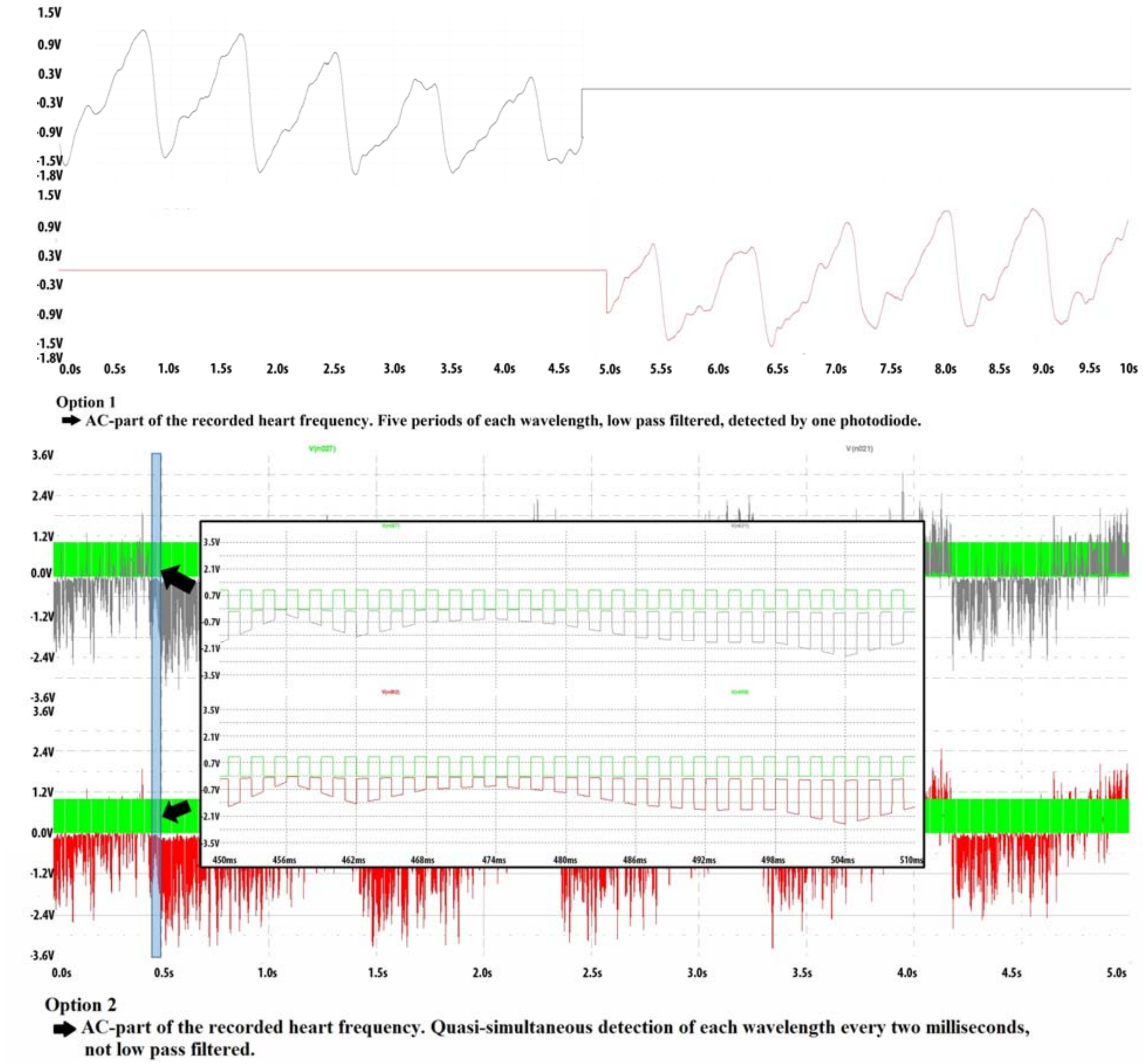

Figure 5. Two options of monitoring results- measurement graphs for different timescales of the measurement procedure.

consumption recommendation could be made, which is independent of the *best-before*-date or other manufacturer's specifications.

Within our department, the developed measurement device is used as a multifaceted measuring platform for the education of students of the "health electronics" study program, as well. Additionally, it will be used for the further development of intelligent algorithms for multimodal signal analysis, which aim to find yet unknown correlations of metabolic processes that could be useful for therapy-supporting or diagnostic procedures.

IV. CONCLUSIONS

We presented the development of a bio-monitoring system measurement device for the acquisition of a variety of information of human tissue or other biological objects. This measurement device detects the pulsatile and non-pulsatile parts by quasi-simultaneous, subsequent one after another, irradiation with light of three different wavelengths and both parts are measured and recorded quasi-parallel. Even without the pulsatile (dynamic) part, the static part of the light reflection is detected. Compared to a conventional pulse oximeter [1][6] our system is extended by electrodes for measuring the bio impedance (a constant current power supply is applied and the voltage drop and the phase shift is measured). A third essential measurement component is a combined sensor for measuring the relative humidity and the temperature on the surface of a measurement object. The bio-monitoring system is designed as a mobile, stand-alone device and therefore, it is equipped with a SD-card slot and a rechargeable battery. Data transfer is also possible via serial communication by a USB port to a PC for further analysis. We intend the development of analysis algorithms for detecting new correlations of the measured parameters on biological objects. A further development is focused to a miniaturization toward a *Lab-on-a-chip* design [12]. Hereby, a simple use for personal health data acquisition and/or a clinical use is thinkable.

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