A Body Sensor Network Based Support System for Automated Bioimpedance Spectroscopy Measurements

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Abstract— **This paper presents the first application of a newly developed Body Sensor Network (BSN), called the *meditBSN*. It is deployed as a support system for mobile bioimpedance spectroscopy (BIS) measurements. BIS measurements are used to monitor the water balance and nutrition status of patients. So far, only stationary measurement devices are available. One reason is that BIS measurements are prone to various influence factors like motion and temperature. Therefore, strict measurement protocols have to be followed to gain reproducible results.**

The NUTRIWEAR project addresses the need for mobile BIS measurements. Solutions are being developed to integrate BIS electrodes into textiles to facilitate handling.

In a first step, three accelerometers were integrated to supervise the activity and the posture of the user. The *meditBSN* uses a dual-radio system (433 MHz ISM band and Bluetooth) to transfer sensor data to a PDA. Software has been developed to automatically start BIS measurements according to the user's context. The complete measurement system was successfully validated with a standard BIS measurement device.

Keywords— **BIS, Bioimpedance, BSN, Body Sensor Network, Influence factors, Motion Artifact, Bluetooth, ISM Band, Accelerometer**

I. INTRODUCTION

The demographic change of societies around the world and the availability of wireless technologies have stimulated a growing research interest in personal health care. The goal of research is to find technical solutions for the upcoming challenges in both society and their healthcare systems. One of the active fields of research is medical sensor networks [1-4]. This paper describes a network of wireless sensors that is directly attached to the patients' body and thus called a Body Sensor Network.

One common phenomenon of the aging human body is a reduced sense of thirst. This can potentially lead to dehydration. Symptoms of mild dehydration are lack of concentration, loss of performance and dizziness. Without immediate supply of water, one could develop more severe symptoms like loss of orientation, unconsciousness up to complete collapse of the cardiovascular system and death, especially during hot summers (like the summer of 2003 in Europe) . Dehydration is a slow process which usually develops over the course of days.

There are several measurement techniques to determine the hydration status of a person. One of them is the dilution method. A specific test solution is injected into the body and the resulting dilution is measured [5]. The disadvantages are the invasiveness as well as the need for a medical professional. An alternative measurement technology is bioimpedance spectroscopy (BIS). BIS uses small AC currents that are applied through electrodes attached to the person's body. A second pair of electrodes is used to measure the voltage drop that is caused by the impedance of the measured body segment (see fig. 1). The electrical properties of different tissue types are frequency dependent [6]. Therefore, up to 50 different frequencies in the range from 5 kHz to 1 MHz are swept. For low frequencies, the current flows mainly outside of the cells because of the capacitive character of the cell membrane. Thus, high frequency currents can flow through both outside and inside of the cells.

A plot of the measurement data is ideally shaped like a semi-circle as shown in fig. 2. In reality, the curve has to be interpolated to estimate the intersections with the real axis [7]. The estimated resistance values are called R_0 (resistance at 0 Hz) and R_∞ (resistance at ∞ Hz). These two parameters are linked to three electrical parameters: R_e (extracellular resistance), R_i (intercellular resistance) and C_m (capacitance of the cell membrane).

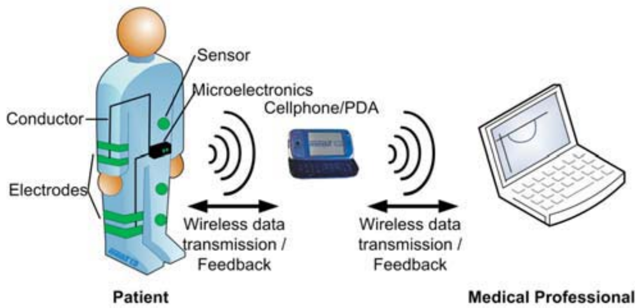

Fig. 1 Measurement setup of the NUTRIWEAR BIS and sensor system for the continuous monitoring of the hydration and nutritional status patient

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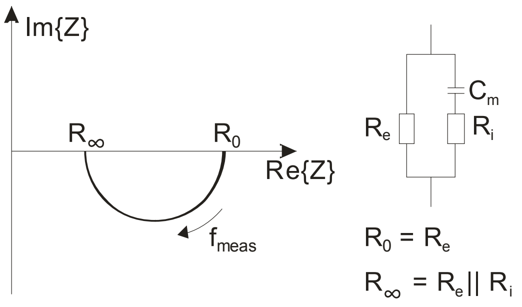

Fig. 2 Cole-Cole model showing the relation between the measurement data and the electrical model

In a second step, the aforementioned electrical parameters are used as input for a model-based approach to differentiate fluid compartments [8]. The simplest model already allows to distinguish the following compartments: extra- and intracellular fluid, lean and fat mass.

However, there are several known influence factors that can have a great impact on the measurement results. These include the following: body position [9], activity [10], skin temperature [11] and ambient temperature [12]. Therefore, it is important to follow a strict measurement protocol in order to obtain reproducible results [12]. This can be accomplished in a clinical, lab or other supervised environments.

Our research efforts are to make the BIS technology available for use in a personal healthcare scenario. Several components have to be developed to achieve this goal:

- A portable BIS measurement device
- Replacement of common adhesive electrodes with textile-based electrodes [13]
- A supervising sensor network [14]

This paper describes the application of a newly developed body sensor network to accomplish the third objective: to supervise and control BIS measurements.

II. MATERIAL AND METHODS

The newly developed wireless sensor network, called the *meditBSN*, was developed to facilitate mobile medical data acquisition. It is based on a modular design of both hardware and software.

The hardware platform consists of a microcontroller (MSP430f1611, Texas Instruments, USA) and a 433 MHz ISM band transceiver chip (CC1101, Texas Instruments, USA). A dedicated connector (Microstac, Erni Electronics GmbH, Germany) is used to extend the base board with sensing capabilities. The sensors can be both digital and analog.

The network is structured in a star topology. The master module is equipped with a Bluetooth extension board instead of a sensor extension board. A dual radio system was implemented to achieve a maximum flexibility, extensibility and customization on the BSN side (433 MHz band) and a standard wireless interface (Bluetooth) to connect to a wide range of standard off-the-shelf end devices, e.g. PDA's, notebooks, etc. on the other side. The data from the sensor boards is send to the master module and then forwarded over the Bluetooth interface to a PDA (MDA Vario III, HTC Corp., Taiwan) as shown in fig. 3. The data stream is analyzed to determine the current context of the user. Additionally, the incoming raw data is stored on the PDA. In a first step, three 10 bit 3-D accelerometers (SMB380, Bosch Sensortec, Germany) were integrated into the sensor network.

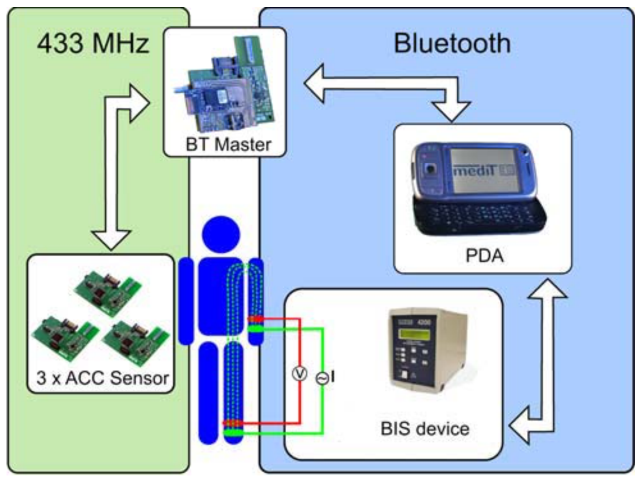

Fig. 3 Schematic of the *meditBSN* showing the accelerometer sensor boards, the master module and the Hydra 4200 BIS measurement device

The posture of the user is recognized by first checking the activity of the user and in case of low activity determining the orientation of each sensor. The complete data set of all three sensors permit the unambiguous determination of the posture. Different postures, e.g. standing, sitting and lying on the back or stomach, are distinguishable. Additionally, a time interval can be defined that prohibits BIS measurements after activities that exceeded an activity threshold. The activity of the user is calculated once a second by adding the absolute differences of the acceleration for two consecutive time points t_0 and t_1 of all three axes as stated in equation 1. A moving average with a definable length is then compared to threshold of acceptable user activity prior to a BIS measurement.

$$A = |x_1 - x_0| + |y_1 - y_0| + |z_1 - z_0| \quad (1)$$

A GUI was programmed for the PDA to easily set the activity threshold and recumbency time (period before starting a measurement) to accommodate for different users. Secondly, the GUI is used to control the actual BIS measurement device. Three different modes of operation are implemented: manual, semi-automatic and automatic. The manual operation mode allows the user to start a BIS measurement regardless of any measurement conditions. The semi-automatic mode signalizes the user after analyzing the measurement conditions, that a BIS measurement may be performed. The automatic mode supervises the sensor information and automatically starts a BIS measurement according to the chosen measurement protocol.

III. MEASUREMENT SETUP

The validation of the sensor network was performed with a standard lab device for BIS measurements (Hydra 4200, XiTRON Technologies Inc., USA). Since the Hydra 4200 is not designed for mobile applications, an electrical dummy was connected to the measurement electrodes to simulate the patient during the data acquisition. A serial-to-Bluetooth adapter (Parani SD400, Sena Technologies Inc., USA) was used to send commands to the BIS device as well as to receive the measurement results.

The *meditBSN* network was used to supervise the test subjects' motion. They were equipped with three accelerometer sensor nodes and one master node. The first sensor was placed on the outside of the lower right leg, the second one on the outside of the right thigh and the third one was placed on the front side of the torso. The measurement protocol was divided into two tests: a static and a dynamic measurement. Different levels of activity and postures were tested as shown in table 1. The sampling rate of the sensors was set to 1 Hz and a sensitivity range of ± 2 g.

Table 1: Static and dynamic activity measurement protocol

Duration	Activity	
Static		
1 min	Sitting	
1 min	Standing	
1 min	Lying	
1 min	Standing	
1 min	Sitting	
Dynamic		
1 min	Walking	4 km/h
1 min	Fast Walking	7 km/h
1 min	Running	10 km/h
1 min	Fast Walking	7 km/h
1 min	Walking	4 km/h
1 min	Lying	-

IV. MEASUREMENT RESULTS

The graphical analysis of the static posture measurement data shows clearly distinguishable signals for each posture. An example of a male 29 year old subject is shown in figure 4.

The dynamic measurement shows distinguishable amplitude and frequency changes for both walking velocities and running. The best signal was recorded on the front side of the torso. It can be seen, that the amplitude of the calculated activity measure *A* correlates well with the intensity of the activity as shown in figure 5.

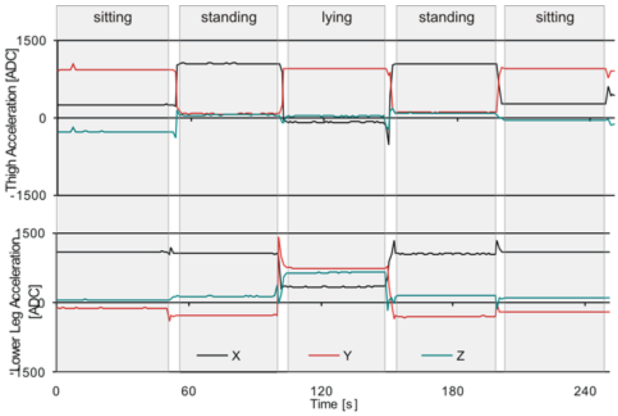

Fig. 4 3D accelerometer data of a thigh and lower leg sensor. The X axis points to the head, Y axis to the front and Z to the right of the test subject. The spikes are caused by the transitional movement between two postures.

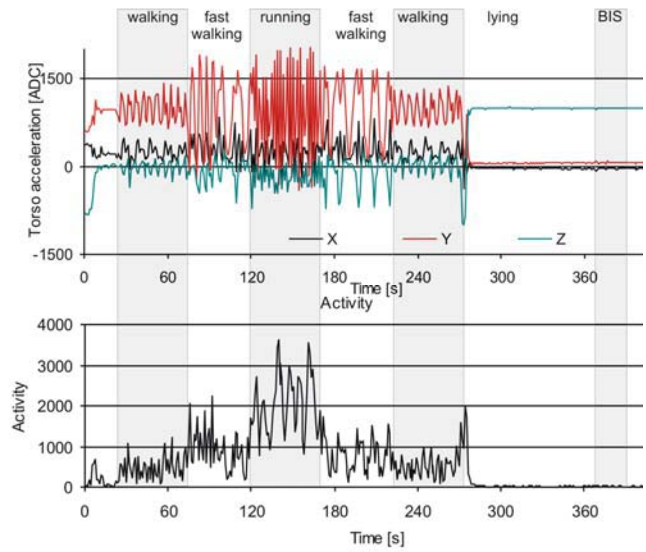

Fig. 5 Torso sensor data of dynamic activity measurement. Below is the resulting activity measure *A*. After a recumbency time of 90 s a BIS measurement is started.

V. Discussion and Conclusion

The acquisition of data over the wireless interface showed some problems due to loss of single data packages. Nevertheless, it could be shown, that even with a sampling frequency of 1 Hz different levels of activity are distinguishable.

A proof of concept of an automatic BIS measurement system was presented. A BSN consisting of three accelerometer sensor nodes, a master node and PDA were used to gather data about the context of the user. Analysis of the accelerometer data permitted to recognize suitable measurement conditions in terms of activity level and posture. An interface to a clinical BIS device was successfully programmed to control and store the measurement data.

VI. Outlook

To further improve the automatic detection of ideal measurement conditions additional sensors can be integrated into the existing network of sensors. A sensor detecting the relative position of limbs to each other would help to reduce the influence of stray capacitance on the measurements. At the same time, short circuits caused by limbs in direct contact with each other, e.g. arms touching the torso, would be detectable. Also, the measurement could be postponed or in case of an ongoing measurement, the measurement could be marked as erroneous.

Additionally, the BIS measurements should be analyzed directly on the PDA to enable direct feedback to the user after measurements.

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