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Review Article

EMBEDDED WEARABLE SYSTEM FOR HYDRATION MEASUREMENT

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ABSTRACT
As far as the human physiology is concerned, water is the most vital element for the overall well being. It plays crucial role in all bodily processes by providing a universal medium. Dehydration is a condition, in which water in a living body reduces unusually, and it is likely to encounter in daily life. Dehydration impairs both physical and mental performance in a human being. The present paper reports conceptualization, design and development of the wearable embedded device for hydration level measurement in the human being. Wearable Medical Devices (WMDs) are the emerging trends in the biomedical domain as they offer patient management system and ensures heath and medical well being by continuous monitoring and thus makes the ubiquitous medical treatment possible that too at minimal cost. Though there are several hydration monitoring techniques, the one used in this paper is bioelectrical Impedance Analysis (BIA).

INTRODUCTION
The medical professionals and the reported literature unanimously agree that water is the most vital for the overall well being in a human being. Interestingly, as babies we are approximately 75 to 80% water and it progressively decrease as we grow older until the percentage is reduced to approximately 60 to 65% for men and 50 to 60% for women (Anonymous 2011). It is also a well established fact that water plays crucial role in all the biological processes in human being for which it serves as an universal medium. This encompasses chemical reactions, lubrication, nutrient delivery, waste disposal, heat dispersion and temperature regulation just to mention a few. It as well plays an important role in circulation, digestion, assimilation of nutrients and oxygen into the cells, and elimination in addition to the biophysical and biochemical processes mentioned previously.
The present focus of the work of the work is assessment of the hydration condition of the human being and detecting the dehydration. Dehydration is a condition, in which the water content in a living body is significantly reduced, and it is likely to encounter often in daily life especially in case of the athletes, workers and the patients suffering from the diseases related to water loss. It goes without saying that maintaining proper hydration conditions is of immense importance in a human being and thus one should stay away from the dehydration as it impairs both physical and mental performance. However, specifically in case of sportpersons, athletes and physical workers, it becomes difficult to exactly detect the juncture at which the dehydration starts. Nevertheless, dehydration or for that matter hydration is a subjective notion difficult to perceive for a human being unless without the expert medical aid. In the backdrop of the importance of the hydration measurement, we report conceptualization, design and development of the wearable embedded device for hydration level measurement in the human being.
The setup developed falls under the paradigm of wearable embedded device with built in intelligence for providing treatment and real time feedback to patients. Cost is generally a constraint especially for the worker class in the developing country. We have focused on this aspect and aims at development of low cost mass produced appliance to determine the hydration. The instrument relies on the bioelectrical Impedance Analysis (BIA) technique which is an emerging tool in the domain of biomedical research. The said BIA principle is one of the well established diagnostic methods based on the study of the passive electrical properties of the biological tissues. It measures the impedance or opposition to the flow of an electric current through the body fluids. In case of our implementation, in order to improve the accuracy, body temperature is also been sensed. The instrument centers around the FPGA in view of the portability,

minimal power consumption and customization as well as reconfiguration on the fly aspects required in the said instrument. However at the first place, it is worthwhile to review the research work put forth by various researchers in this field.

Prior Art

There are few instances of instrumentation for the hydration measurement in the literature. Recently Gunter et. Al. have reported a new MEMS based sensor technology, embedded piezoresistive microcantilever (EPM) sensors. The volumetric changes in osmalarity in a person's saliva are measured by tiny piezoresistive micro cantilevers embedded in the polymeric material (Gunter et al., 2007). Kohli recommend in her paper that in a number of reports suggest that skin impedance provides a useful non-invasive method for assessing skin hydration. It has been found that wide inter-subject and intra-subject variations in skin impedance are present. Experiments involving stripping of the stratum corneum suggest that in measuring skin impedance the area of skin immediately below the electrodes rather than that between the electrodes determine the value obtained (Kohli et al., 1985).The Corneometer® CM 825 (Anonymous 2003) are the only skin testing instruments which is based on the measuring principle of capacitance measurement of a dielectric medium. Any change in the dielectric constant due to skin surface hydration variation alters the capacitance of a precision measuring capacitor (Morrison et al., 1996). However a major gap in the literature survey reveals that there is no instance of wearable instrument for hydration measurement based on FPGA and by using the BIA principle. Therefore we decided to use the well established BIA principle in the biomedical domain for diagnostics of other diseases for the dehydration detection. Before covering the main instrument aspect, the following section covers the few basic aspects regarding the human body essential to set the background of the proposed development with respect to intracellular and extracellular hydration content.

Body Composition Compartments

Body fat mass, fat-free body mass and body water are basic components of body composition which are used in nutritional and metabolic studies and in patient care. For the molecular and higher levels of the multilevel model, the single molecule that constitutes the highest fraction of body mass is water[9]. The protein and fat component are relatively small, with the remainder being primarily bone and minerals. In healthy adults, TBW constitutes ~73% of the FFM or 60% of body weight for non-obese subjects. At full-term birth, a healthy infant's TBW is typically 80–83% of FFM, which then decreases rapidly over the next 3–5 yr until the hydration fraction reaches that observed for adults. All of the water content inside the cells is termed intracellular water and it represents around 2/3 of the TBW & extracellular water is nothing but outside the cells and it represents around 1/3 of TBW. The change in hydration reflects a change in the ratio of water between the intracellular and extracellular compartments. With the basic details of the hydration content in place, the following section covers the electrical model of the cell which is the basis of the proposed instrument.

Electrical Model Of Cell

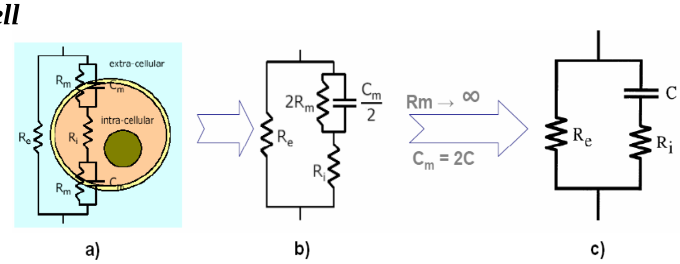

Figure 1. Equivalent circuit of a cell where Re is the extracellular fluid Resistance, Ri is the intracellularfluid Resistance, Rm is the trans-membrane ionic channel Resistance and Cm represents the cell membrane Capacitance.

Retrieved from Final Degree Thesis (2009) Entitled "Towards Wearable Spectroscopy Bioimpedance Applications" by RAÚL MACÍAS MACÍAS, University of Boras p. 9

Electrical properties of tissues have been described since 1871. These properties have been further described for a wider range of frequencies on larger range of tissues, including those that were damaged or undergoing change after death (Kyle, 2004). The ability of tissues, and therefore the whole body, to conduct an electric current has been recognized for more than a hundred years. Thus the core principle which is the sole basis of our instrument has a historical evidence of more than 100 years. As reported in the aqueous tissues of the body, due to their dissolved electrolytes, are the major conductors of an electrical current. Researchers have applied theory of electrical circuits, to derive an explanatory and descriptive electrical model for the cell. One such model reported by Raul in (Macías 2009) is shown in fig. 1. At low frequency, the current is not able to penetrate the cell because of the plasma membrane acting as an insulator. At high frequency, the insulator effect of the plasma membrane decreases and the current flows through the intra and extracellular fluid. Thus the cell serves as an variable impedance appliance, wherein the impedance is a function of the frequency of the current being applied. These further sets the above mentioned property of the cell to formulate the principle of BIA as presented in the following section.

Principle Of Bioelectrical Impedance

The application of the bioelectrical impedance analysis (BIA) has been popularly used both in healthy subjects and patients, however suffers from a lack of standardized method and quality control procedures. As revealed from (Macías, 2009) and (Kotler, 1996), which also reports analytical treatment pertaining to the BIA, the technique can be potentially used for determination of the fat-free mass (FFM) and total body water (TBW) in subjects without significant fluid and electrolyte abnormalities, when using appropriate population, age or pathology-specific BIA equations and established procedures. Bioelectrical impedance analysis (BIA) is a method which measures the impedance or opposition to the flow of an electric current through the body fluids contained mainly in the lean and fat tissue. The impedance of a volume conductor is obtained depends on the electrical properties of the material and the shape and orientation respect the Electrical Field. In the case of a cylindrical volume, the resistance of a length of homogeneous conductive material of uniform cross sectional area is proportional to its length and inversely proportional to its cross sectional area,

$$R = \rho \frac{L}{A}$$

Although, the body is not a uniform cylinder and its conductivity/resistivity is not a constant. A relation between the volume of body water established as,

$$V = \rho \frac{L^2}{R}$$

Where, Volume is nothing but Total body water, Length is the subject height and R is the resistance of the body which measures using the BIA analysis and the value of the coefficient is depends on the several factors such as gender, age, weight[12][14] . Based on the analytical treatment and theoretical models put forth in [12] and [14], we now present our design of the instrument for hydration measurement.

Design Of The System

As mentioned in the previous sections, in order to determine the hydration the bioelectrical Impedance Analysis (BIA) technique has proved to be the most worthy out of other possible sensing techniques. The basis of the detection principle is the change in the BIA with changing water level and body temperature. (When the human body temperature goes up the BIA decreases) The dehydration condition is detected by correlating the change in the BIA with change in the body temperature based on the equ. 1, the details of which are further covered in (Kushner, 1986).

$$\text{TBW (liters)} = a * \text{HEIGHT}^2 / R + b * \text{WEIGHT} + c * \text{AGE} + d \qquad \text{…....(1)}$$

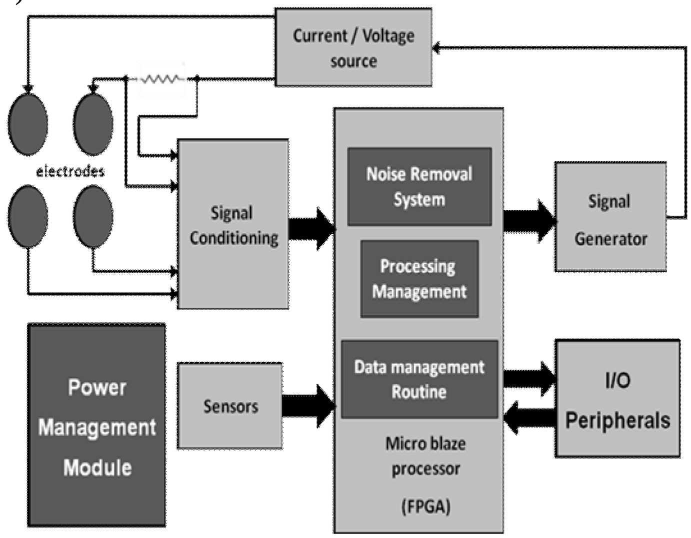

Figure 2. Schematic of hydration measurement system

The system schematic is shown in above fig. 2. The equ. 1 has been computationally implemented in terms of the soft processor core instantiated in FPGA. The potential (V) and the current (I) applied through the probes are correlated, integrated, digitized and divided in order to determine the value of R_X which is further calibrated stored and displayed. The system has a provision to input various parameters such as gender, age, weight of the subject in order to derive quantification of water on the LCD, after processing through the appropriate look up tables. The major constituents of the system are the constant current source with less than 1 mA at 50 KHz which is applied through the outer electrodes. Whilst the inner electrode sense the voltage flowing through the body tissue in order to estimate the impedance. The digital temperature sensor has also been employed for body temperature measurement to improve the accuracy of the system. Proper digitization is ascertained and sufficient time allowed to elapse through the timer mechanism to reconcile the biological process. The coefficient mentioned in above equation is stored in the register array in the soft IP processor core implemented in the FPGA. Processing management calibrates the tables as per the gender, age, height and weight is used as a look-up table. The total amount of body water in terms of percentage is displayed on the display device. LCD has been used as an ASCII display while provision of an alarm is also kept to indicate dehydration condition.

Conclusion

Proper hydration is helpful for achieving the best performance in all physical and mental level. The reliability and validity of current hydration assessment methods and criteria such as thirst, skin turgor, blood pressure, pulse, urine output and specific gravity, MRI, dilution methods have limited accuracy. Besides these methods are far from cost effectiveness and portability. The reported handy device is very useful in ubiquitous monitoring of the total amount of percentage of water level in the body by measuring bioelectrical impedance value. The said instrument also provides an early dehydration warning and thus saves the subject from dangerous conditions.

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