

Effect of Changing Body Fluid Levels on Intrabody Signal Propagation

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Abstract. Intrabody signal propagation uses human body tissue as the communication medium. Human body tissue consists of various components in aqueous medium which are electrolytic in nature. Changes in the amount of water in the body changes the volume of the body fluid which in turn alters the overall impedance of the tissues. These changes affect the signal attenuation of an electrical signal passing through those tissues. We investigate the effect of body fluid changes on intrabody signal propagating between 900 kHz and 1.5 MHz. Our empirical measurements on 6 subjects show that within the first 20 minutes after intake of 600 ml of water, a propagating galvanic coupled signal would have maximum rate of signal gain occurring between 900 kHz and 1.1 MHz. Understanding that rate at which the signal changes due to changes in body fluid level can be used for investigating human body hydration patterns with potential application in diagnosing or monitoring body fluid disorder and diseases associated with loss or rapid gain of body fluid.

Keywords. Galvanic coupling, Signal attenuation, Body fluid levels, Hydration rates

1. Introduction

Intrabody communication (IBC) uses human body tissue as the medium for signal transmission. Research in this area has increased improvements in understanding human body electromagnetism, body implant technologies, healthcare sensor technologies and in-body communication systems. In galvanic coupling IBC system, the signal is applied differentially between a pair of transmitter electrodes and received equally differentially by the opposite pair of receiver electrodes. The electrical signal propagating through tissues are influenced by frequency-dependent dielectric properties of the tissues. This is necessitated by the presence of electrolytes in the tissues with electrolytic conductivity which cause potential differences that influence current flow. The high conductivity of body fluid in relation to other tissue components implies that changes in the body fluid volume will affect the overall tissue impedance which would cause an increase or decrease in the signal amplitude when passed through a body with dynamically changing fluid level. Signal attenuation on tissues are higher at low frequencies due high relative permittivity of tissues at lower frequencies, consequently we can use the changes in attenuation at low frequencies to measure the effect of varying fluid volume on an intrabody signal

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propagating across human tissue. Fig.1 and Fig.2 depict the dielectric relationship with frequency of common human tissues. The dynamic changes in the body fluid volume is understood in the average quantity of water consumed by a normal person to replace lost fluid in a temperate environment which is estimated between 2600 - 2700 ml per day [1]. Water contributes up to 60% of total body weight of an adult [2]. This amount is not constant, the body loses substantial amount of water through the urinary system, respiratory system, evaporation, sweating, vomit and excretion. On the other hand, body water can be gained through consumption of food and drink and absorption through direct skin contact. These processes show a constantly varying fluid level that are affected by the individual metabolism, environmental condition and physical activity which in turn causes a time-varying change in the impedance of the body. We propose that the magnitude and rate of individual specific water loss or gain affects the magnitude and rate at which a galvanic signal attenuates or amplifies when propagated across the human tissue.

Understanding the effects of changing body fluid levels in intrabody communication would assist designers to make appropriate prediction of signal behaviour rather and avoid previous assumptions of a static tissue impedance characteristic [3][4][5]. A dynamic tissue impedance that would respond to daily variable fluid changes is necessary because of the potential application for biomedical technology. Also qualitative measurement of the changes in body fluid volume using IBC signal characteristic changes can be used for estimating hydration rates and changes in body fluid volume [6] and for monitoring instances of body fluid disorder.

In this paper, we investigate the effect of real time changes in human body fluid levels on a galvanic coupled signal propagating through the human tissue in both hydration and dehydration states of human body fluid. The rest of this paper is divided into section II tissue impedance models, section III experiments, section IV results and section V conclusion.

2. Tissue impedance models

To investigate and predict the propagation behaviour of IBC signal by either capacitive or galvanic coupling, a model of the human body tissue is used. Although, there are at present several models in use, large discrepancies still exist between empirical results and model predictions [7]. To reduce the discrepancies to manageable level requires fundamental study of the tissues and analysis of the empirical data for potential source of error. Generally, the analysis of tissue responses to applied electrical potential is examined based on its specific conductivity and relative permittivity over a range of frequencies. This principle has been used by various authors to model human tissue either as finite-element method which has the disadvantage of considerable computational overhead but positively adopted because it includes both elements of the body and components created by the propagating signal such as electric field, the current density around the propagating medium and effects of other parameters such as channel length and inter-electrode distance on the propagating signal [8-9]. Finite difference time-domain (FDTD) methods requires an electromagnetic field in the simulation area to operate [10]. FDTD is equally time consuming and particularly unsuitable at low frequency. The human body equivalent electric circuit model [3-4] in its original form was first proposed by Zimmerman [11] as consisting of four transverse and longitudinal impedances between the transmit and re-

ceive electrodes. This model was used in capacitive coupling channel circuit impedance calculation but did not include the inter-electrode impedance between the transmitter and receiver. Subsequently Wegmueller et al [9] proposed a four terminal model with five body tissue impedances and four terminal electrodes which has been widely used in galvanic coupling circuits. However, Song et al [3] reconsidered the human geometry of this model and approximated it to a homogeneous solid volume and also included an output impedance coming from the transmitter and input resistance from the receiver. Each of these models follow a consistent assumption of a static impedance property of the conducting tissues. We proposed a time-varying first-order model of human body channel, with variable tissue impedance [6]. In this work, we shall investigate empirically the effect of changing body fluid volume on intrabody signal propagating across the human body on six subjects. We used the dynamic changes in the body fluid volume to propose a dynamic tissue impedance given by

$$Z_F(t) = Z_{f0} - Z_w(1 - e^{-\frac{t}{\tau}}) \quad (1)$$

where t is the time for the change in impedance to occur, Z_{f0} is the impedance at time $t = 0$ before the change in the body fluid level occurs, t_f is time to reach the state where no more fluid is absorbed, Z_w is the impedance resulting from the water consumed and the ratio $\frac{t}{\tau}$ is a characteristic that predicts the rate of hydration. τ is the time constant that characterises a particular individual. And the change in the amount of body fluid V_b , assuming an initial fluid volume V_{ib} before fluid intake when V_w amount of fluid consumed is given by

$$V_b = V_{ib} + V_w e^{\frac{t}{\tau}}; t = 0; V_b = V_{ib} \quad (2)$$

Therefore the body fluid volume changes dynamically with respect to time t . If V_w amount of water is consumed by the subject, after time t , the tissue fluid level would have increased by $V_w e^{\frac{t}{\tau}}$ amount absorbed into it which would change the tissue impedance from Z_{f0} to $Z_F(t)$. Thus the general behaviour of a simplified galvanic coupled signal propagating through the body (Fig.4) is governed by $G(f, t, \tau, \theta)$, where f is the input signal frequency, t is the real time of observation, τ is specific to time varying endogenous metabolic characteristic of the subject that affects the rate of hydration, and θ is a function of the individual anthropometric measurements. We shall use this relationship to measure empirically the effect of varying fluid level on galvanic coupling intrabody signal at 1.1 MHz on 10 subjects.

3. Experiment

The measurement set-up is as shown in Fig.4. A mini Pro VNA, frequency range 100 kHz to 200 MHz, manufactured by Mini Radio Solutions, baluns (Coaxial RF transformers, FTB-1-1+, turns ratio of one, manufactured by Mini-Circuits, and frequency range 0.2-500 MHz), and round pre-gelled self-adhesive Ag/AgCl snap single electrodes (1 cm diameter, manufactured by Noraxon) were used. The baluns were used to electrically isolate the two ports of the VNA to ensure the return current does not pass through the common earth ground of the two ports. The VNA is set to sweep the constant interval frequency of range 300 kHz to 5.4 MHz in 49 points with 0 dBm output power. This is

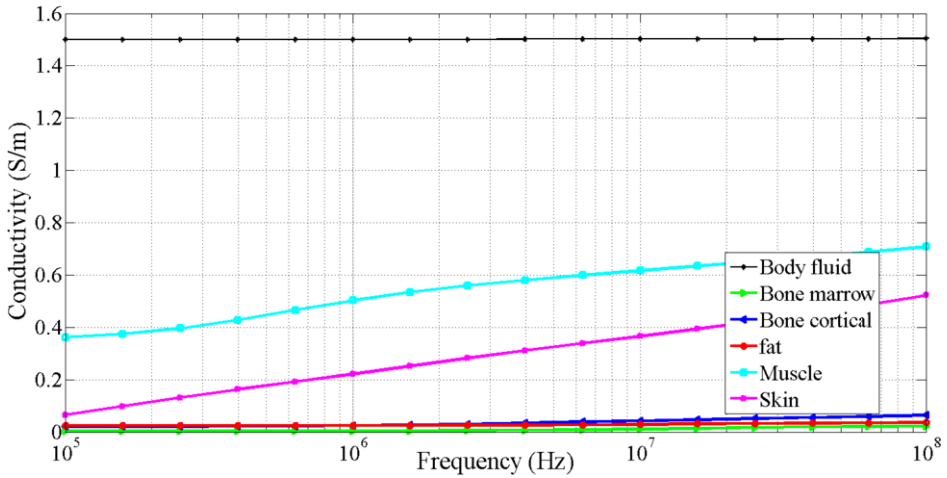


Figure 1. Conductivity (S/m) of tissues at different frequencies. Data source [15]

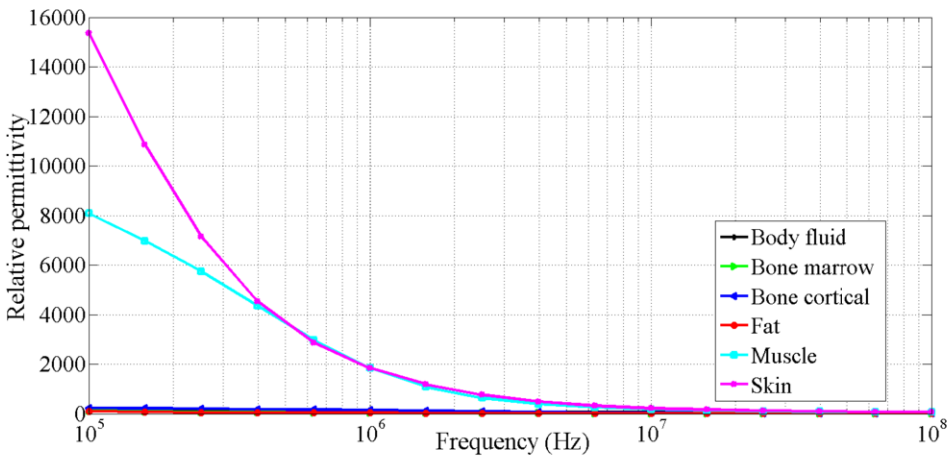


Figure 2. Relative permittivity of tissues at different frequencies. Data source [15]

well below the safety limit set by International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998) and World Health Organization (WHO, 1993) [12]. The Noraxon self-adhesive Silver/Silver-Chloride electrodes (Ag/AgCl) are preferred because it reduces the effects of motion artifacts and signal reflection. The distance between the transmit and receive electrodes and the inter electrode separation is 20 cm and 4 cm respectively [13]. A small harmless electrical current (<1 mA) is transmitted into the arm via a pair of Noraxon surface electrodes (transmitter electrodes) and received 20 cm at the receiver end as shown in Fig.5. Six healthy volunteers participated in the ex-

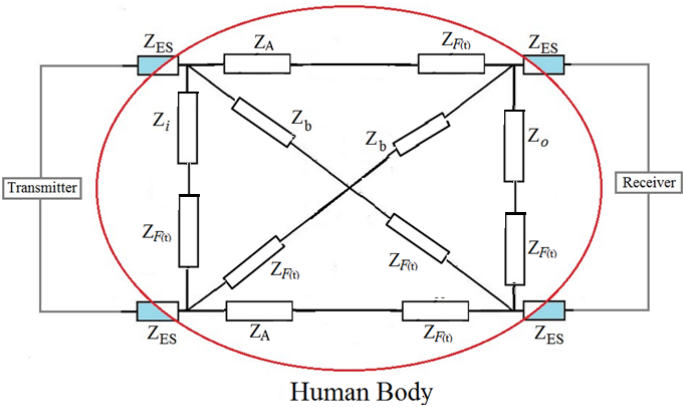


Figure 3. Galvanic coupled IBC circuit with variable impedance [6]

periment. First the subjects were asked to abstain from fluid after supper to 10.00 am. The subjects were given 600 ml of water and measured separately after fluid intake and after urination. All the subjects sat on a plastic chair with arms by the side to ensure the current was confined within the arm and avoiding external physical contact with conducting any material. Since individual metabolism is different at different times of the day, our experimental protocol was designed to ensure that all measurements were done at 10.00 am and that the average room temperature was maintained at $25 \pm 0.1^{\circ}\text{C}$. Repeated measurements were taken after abstinence from fluid and at 5 minutes interval following fluid intake of 600 ml of water and the average used to minimise measurement uncertainties. The subjects were again measured in the same manner after urinating. The elapsed time to urinate and the volume of urine produced were also recorded. All the experiments and recruitment of the subjects followed ethics procedures mandated by the Victoria University Human Ethics Research Committee.

4. Result

Fig.5 depicts the change in time of a galvanic coupled signal propagating at 900 kHz and 1.1 MHz. The signal gain increased in time on all the subjects up till 20 minutes after intake before it began to decrease on subjects A, C and D but continued to increase on subjects B, E and F. At 1.3 MHz and 1.5 MHz, only subjects B and F had the signal propagating through them increasing in gain beyond 20 minutes. Also different subjects had different times at which the signal began to increase in gain and different rates at which the signal gained as it propagates across the tissues. At 900 kHz, the maximum gain after 600 ml of fluid intake varied from 0.44 dB/minute to 0.47 dB/minute on subjects B and C while the minimum rate was observed on subjects A and D at the rate of 0.35 and 0.37 dB/minutes respectively. Similarly, at 1.5 MHz, maximum rate at which the signal gained in strength was found on subject B at the rate of 0.31 dB/minute while the minimum occurred on subject E at 0.18 dB/minute.

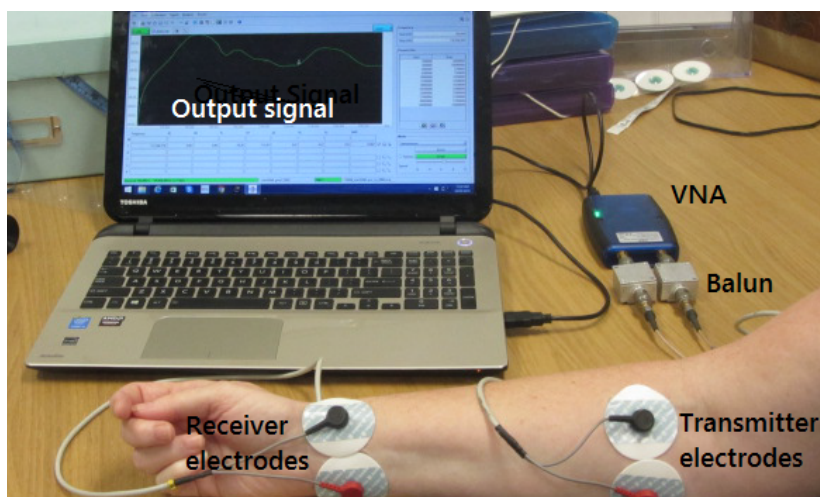


Figure 4. Galvanic-coupling circuit on the lower left arm, the four terminal silver-silver chloride surface electrodes are attached to the body and connected to the VNA via a balun. The output signal shows on the laptop screen fitted with the VNA software

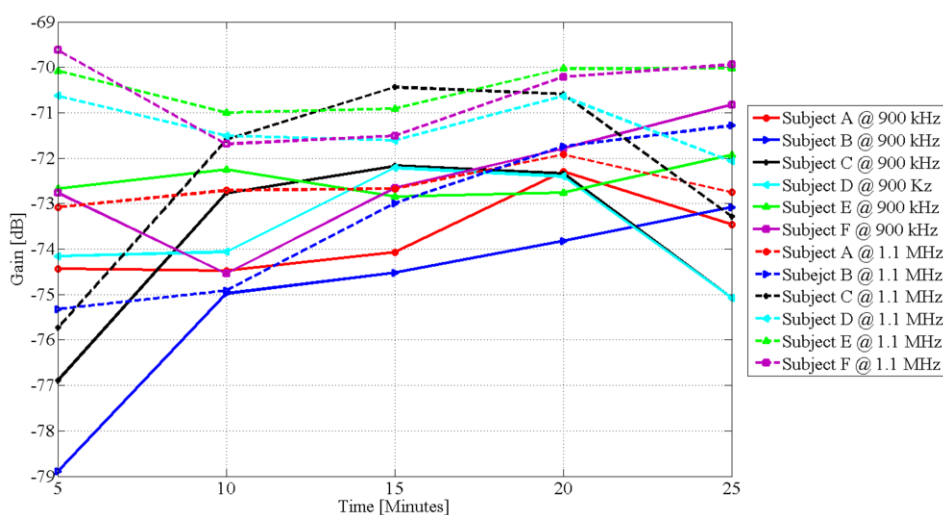


Figure 5. Effects of changing body fluid on intrabody signal propagating at 900 kHz and 1.1 MHz on 6 subjects after consuming 600 ml of water

5. Discussion

This experiment shows that changing body fluid level changes the signal amplitude of a galvanic coupled signal propagating across human tissues and the rate of change depends on the observed frequency. This principle can be observed in Figs.1 and 2 which suggests that the high conductivity of body fluid and the permittivity at low frequency will make a propagating galvanic coupled signal to amplify if the fluid level increases or attenuate

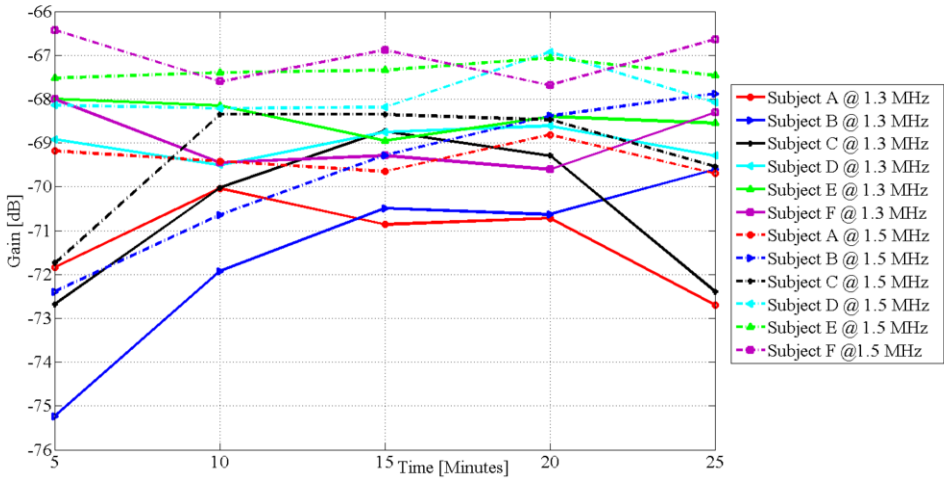


Figure 6. Effects of changing body fluid on intrabody signal propagating at 1.3 MHz and 1.5 MHz on 6 subjects after consuming 600 ml of water

if the fluid level decreases. A 2011 report by Lisa et al suggested that body fluid losses during exercise can cause up to 6 % increase in muscle impedance [16]. This means that a human body communication model should include the effects of there random changes in fluid level. Furthermore, the rate, duration and magnitude of the signal gain or loss varied per subject. This can be attributed to subject specific body composition [13], as well as the level of demand for water by the tissues. It has been suggested that physiological factors such as age, gender and height affects human body metabolism [14] which affects body fluid levels. At frequencies above 500 kHz, an electrical signal propagating across living tissues passes through both the extracellular and intracellular fluid spaces [17]. The combined impedance produced by the tissues and cell membranes affects the magnitude of the signal gain or loss experienced. This principle has been used in estimating total body water in a multi-frequency bioimpedance technology. However, wireless body area network proposes a human body communication at frequencies centred at 21 MHz. In designing the human body communication system, care should be taken to cater for the effects of varying signal amplitudes as a result of changes in body fluid level which occur daily. Also the wearable body area network device can be integrated to read the rate at which body fluid changes which can predict hydration and suggest rehydration times.

6. CONCLUSIONS

In this paper we show that intrabody signal amplitude changes as body fluid level changes. The change in the body fluid level affects the overall impedance of the body tissues through which the signal passes. Thus, a human body channel model should incorporate a variable fluid impedance. The rate of change can be used for investigating human body hydration patterns and body fluid levels which has potential application in diagnosing or monitoring body fluid disorder and diseases associated with loss or rapid gain of body fluid. However, a baseline value of an individual’s fluid level is required in

order to assess the hydration rates and changes in body fluid level. In future, we shall establish a mathematical relationship between the amount of fluid in a particular tissue space and the attenuation experienced at 900 kHz and 1.1 MHz and investigate the possibility of using it to monitor body fluid disorder.

References

- [1] P. O. Astrand and K. Rodahl, *Textbook of work Physiology, Physiological Bases of Exercise*, 3rd ed. New York: McGraw-Hill Book Company, 1986. pp. 412-485.
- [2] E. Jquier, and F. Constant, "Water as an essential nutrient: the physiological basis of hydration", *Eur. J. Clin. Nutr. vol.*, 64, no. 2, pp. 115-123, 2009,
- [3] Y. Song, Q. Hao, K. Zhang, M. Wang, Y. Chu, and B. Kang, "The simulation method of the galvanic coupling intrabody communication with different signal transmission paths." *IEEE Trans. Instrum. Meas.*, vol. 60, no.4, pp. 1257-1266, Apr. 2011.
- [4] B. Kibret, M. Seyedi, D. .T. H.Lai, and M. Faulkner, "Investigation of Galvanic Coupled Intrabody Communication using Human Body Circuit Model," *IEEE J. Biomed. Health Inform.*, vol. 18 no. 4, pp. 1196-1206, 2014.
- [5] S. H. Pun, Y. M. Gao, P. Mak, M. I. Vai, and M. Du, "Quasi-static modeling of human limb for intra-body communications with experiments," *IEEE Trans., Inf. Technol. Biomed.*, vol.15, no.6, pp. 870-876, Nov. 2011.
- [6] C. O. Asogwa, A. Teshome, Collins. S, and D. .T. H.Lai, "A Circuit Model of Real Time Human Body Hydration," *Accepted. IEEE Trans. Biomed. Eng.*, vol. 99, Oct. 2015.
- [7] M. Seyedi, B. Kibret, D. .T. H.Lai, and M. Faulkner, "A survey on intrabody communications for body area network applications," *IEEE Trans. Biomed. Eng.*, vol. 60 no. 8, pp. 2067-2079, 2013.
- [8] R. Xu, H. Zhu, and J. Yuan, "Electric-field intrabody communication channel modeling with finite-element method," *IEEE Trans. Biomed. Eng.*, vol. 58, no. 3 pp. 705-712, Mar. 2011.
- [9] M. .S. Wegmueller, A. Kuhn, J. Froehlich, M. Oberle, N. Felber, N. Kuster, and W. Fichtner, "An attempt to model the human body as a communication channel," *IEEE Trans. Biomed. Eng.*, vol. 54, no.10, pp. 1851-1857, Oct. 2007.
- [10] K. Fujii, M. Takahashi, and K. Itao, "Electric field distributions of wearable devices using the human body as a transmission channel," *IEEE Trans. Antennas Propag.*, vol. 55, no.7, pp. 2080-2087, Jul. 2007.
- [11] T. G. Zimmerman, "Personal area networks: near-field intrabody communication," *IBM Systems Journal*, vol. 35, pp. 609-617, 1996..
- [12] A. Ahlbom, U. Bergqvist, J. Bernhardt, J. Cesarini, M. Grandolfo, M. Hietanem, A. Mckinlay, R. Repacholi, D. Sliney, and J. Stolwijk, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). International commission on non-ionizing radiation protection," *Health Phys.*, vol.74, no.4, pp. 494-522, Oct.1998.
- [13] C. O. Asogwa, M. Seyedi, and D. .T. H.Lai "A preliminary investigation of human body composition using galvanically coupled signals," *In Proceedings of the 9th International Conference on Body Area Networks. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering)*, pp. 346-351, Sept. 2014.
- [14] M. D. Mifflin, S. T. St Jeor, L. A. Hill, B. J. Scott, S. A. Daugherty and Y.O. Koh, "A new predictive equation for resting energy expenditure in healthy individuals," *Am. J. Clin. Nutr.*, vol. 51, no.2, pp. 241-247, 1990.
- [15] D. Andreuccetti, R. Fossi, and C. Petrucci, *An Internet resource for the calculation of the dielectric properties of body tissues in the frequency range 10 Hz - 100 GHz*, Website at <http://niremf.ifac.cnr.it/tissprop/>. IFAC-CNR, Florence (Italy), 1997.
- [16] L. Rothlingshofer, M. Ulbrich, S. Hahne and S. Leonhardt, "Monitoring change of body fluid during physical exercise using bioimpedance spectroscopy and finite element simulations," *Journal of Electrical Bioimpedance*, vol.2, no.1, pp.79-85. 2011.
- [17] J. Nyboer. "Workable volume and flow concepts of bio-segments by electrical impedance plethysmography." *TTT. J. life Sci* vol.2, no.1, pp.1-13, 1972.