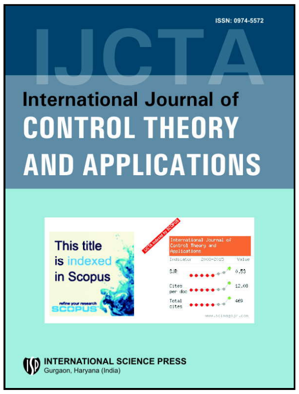

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Analysis of on-body-Antenna Distance on Reflection Coefficient and SAR values for WBAN Application using PSO

Kusum Grewal Dangi[1], Supriya P. Panda[2] and Amita Bhagat[3]

[1] *Department of Electrical, Electronics and Communication Engineering The NorthCap University, Gurugram, Haryana, India, Email: kusumgrewal@ncuindia.edu*
[2] *Department of Computer Science and Engineering Manav Rachna University, Faridabad, Haryana, India, Email: supriyap15@yahoo.com*
[3] *Department of Applied Sciences The NorthCap University, Gurugram, Haryana, India, Email: amitabhagat@ncuindia.edu*

Abstract: The trend of networking has exploded exponentially in the recent past. It has become the basic building blocks of modern society and commonplace entities in all aspects of life. The next evolution of the Internet, internet of things (IoT) is promising a huge leap in its ability to close the gap between poor and rich. In this paper, we are focusing on the performance analysis of the effect of the wireless body area network (WBAN) technology in symbiosis with human beings. Two major problems stated in this paper are effect of human on antenna wave propagation and effect of antenna wave propagation on humans. The matrices considered for evaluation are distance between human body and antenna for on-body sensor, reflection coefficient and specific absorption rate. Particle swarm optimization (PSO) is used to estimate the values of these parameters. Human body is treated as a dielectric medium for this analysis.

Keywords: Internet of Things (IoT); dielectric properties of biological tissues; Wireless Body Area Network (WBAN); Particle swarm optimization (PSO).

1. INTRODUCTION

There is a major paradigm shift with the advancement in networking technologies and advent of micro-electromechanical sensors (MEMS) technology. These days the applications of networking are not limited to the simple connection of wide area and local area network for sharing files but has reached to the applications which are related to remote sensing, health sensing and other applications which have ample social impact [1]. The growing applications and prominent increase in the networking devices having passive and/or active antennas, has stimulated the quest of researchers for valuation and quantification of the impacts of radio waves on human health.

In this paper we are considering the wireless body area networks (WBAN) for health monitoring [2]-[4]. WBAN consists of wireless sensors which are either body worn or implanted inside the human body. These sensors form a network which is responsible for sensing, processing and communicating the physiological vital medical signals to the hospital information system (HIS) for further analysis. The inter-sensor communication involves the on-body (human) signal propagation, in-body (human) signal propagation, reflection coefficient (s_{11}), specific absorption rate (SAR) and distance (D) between the body-worn sensor and human body.

Further, in section II the dielectric properties of human body at various frequency bands are discussed; in section III we discuss about effect of human body on wireless communication model while section IV presents the factors affecting on-body communication. The methodology stating optimization problem for SAR and s_{11} has been formulated in section V. Section VI concludes the paper with results and discussions.

2. DIELECTRIC PROPERTIES OF HUMAN BODY

Human body is a complex structure made up of materials having different densities and electro-chemical and electromagnetic properties. Many papers are present in literature which has studied human body and biological tissues for their dielectric patterns at RF and microwave frequencies. In [5] Gabriel measured the dielectric properties of over 20 tissue types including human tissues in the frequency range of 10 Hz to 20 GHz. In the internet article on "interactions between electromagnetic fields and biological tissues" [6] the author states that the biological tissues of human body are transparent to magnetic fields; and dielectric properties of human body are strong functions of frequency and can be considered as lossy dielectric.

The dielectric properties of materials are obtained from their measured complex relative permittivity (å*) and conductivity (ó) [7]. It is mathematically expressed as mentioned in equations (1) and (2):

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

$$\varepsilon^* = \varepsilon' - j\frac{\sigma}{\omega} \quad (2)$$

where ε' is dielectric constant, ε'' is dielectric loss factor, σ is conductivity of medium in (S/m) and ω is frequency of the applied field. The absolute permittivity of vacuum, ε_o, is determined by equation (3):

$$c_o^2\mu_o\varepsilon_o = 1 \quad (3)$$

where c_o is speed of light and μ_o is magnetic constant.

The other factor that governs the measurement of dielectric property is the depth of penetration (d_p) which is defined as the distance at which microwave power has been attenuated to 50% of transmitted power. It is a function of ε' & ε'' and represented as equation (4):

$$d_p = \frac{\lambda_0\sqrt{\varepsilon'}}{2\pi\varepsilon''} \quad (4)$$

where λ_0 is free space microwave wave length in meters.

In paper [8] the authors stated that the dielectric properties of human tissues are age dependent. The depth of penetration is more in the children than the adult. Paper [9] mentions that dielectric constant often varies due to the variations in physiological anatomy of body like skin thickness, fat layer and muscle strength.

3. EFFECT OF HUMAN BODY ON WIRELESS COMMUNICATION

In literature human body is defined as cylindrical antenna [10] and also, as mentioned in section II, human body is a dielectric medium therefore it interfere with the normal functioning of the sensor's antenna in WBANs. The effected parameters of performance of sensor antenna are its radiation pattern, efficiency, resonant frequency, input impedance etc [11].

The sensors in WBAN can be body worn or implanted inside, therefore the effective distance of the antenna form the human body may disturb the antenna matching. Paper [12] and [13] consider the human body-antenna distance as parameter of measurement of the change of antenna matching. In [13] the authors have considered two planner ultra wide band (UWB) antenna, the simulations were carried out and found that S_{11} (reflection coefficient) was variable when the distance of the antenna from human body was varied. The signal was found of better quality when the distance from body was significantly high. Similarly, paper [14]confers the interaction of human body with two half-wavelength dipole antennas and Paper [15] considered a compact higher mode microstrip patch antenna (HMMPA) for the on-body communication and measured $|S_{21}|$ i.e. path gain between two mounted antennas and found significant change is gain when D was increased.

4. FACTORS EFFECTING ON-BODY WIRELESS COMMUNICATION

In frequency spectrum, all frequencies have their own properties related to propagation and fading effects. Broadly the spectrum has been divided in 4 ranges for the analysis of energy absorption by human body at a particular frequency [16]. These ranges are from (100 KHz to <20 MHz), (20 MHz to 300 MHz), (300 MHz to <10 GHz) and (>10 GHz). In 100 KHz to <20 MHz the significant absorption occurs at neck and legs; the whole body has relatively higher absorption rate in 20 MHz to 300 MHz. While band 300 MHz to <10 GHz has local and non-uniform absorption pattern. While frequencies above 10 GHz are relatively unable to penetrate the human body and can produce only heating effect on body surface.

While on-body communication is being considered the inter-sensor parameters are considered like along the body signal propagation, distance of sensor antenna from human body, depth of penetration and specific absorption rate (SAR) values. SAR is defined as the measure of power absorbed per unit mass of tissues when exposed to radio frequencies. It is has units of Watts per Kilogram (W/Kg). The SAR for electromagnetic energy can be calculated from the electric field within the tissue as shown in equation (5):

$$\text{SAR} = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{\sigma E^2}{2\rho} \tag{5}$$

Where E is induced electric field strength in Volts/meter, ρ is tissue density in Kg/m^3 and W is absorbed energy in Joule

When a tissue remains in continuous exposure of RF signal for a prolonged duration, the changes in its temperature can be expressed as equation (6):

$$\Delta \text{T} = \frac{(SAR)\Delta t}{C} \tag{6}$$

Where, ΔT is the expected rise in temperature in Kelvin, C is the specific heat capacity expressed in J/kg K and ΔT is time for which the tissues were exposed to RF field in seconds.

In papers [17-20] experiments were carried out on antennas working in the frequency range of 2.45 GHz for the application of WBAN for health monitoring , and was found that if the sensor antennas are placed at a enough distance above the human body, the SAR values were found within allowed limits (1.6 Watts/Kg)

V. METHODOLOGY

The optimization of SAR and s_{11} with respect to D is done using particle swarm optimization (PSO) algorithm. PSO simulates the behavior of bird flock, in search of food who knows the distance from food but not the location. Initially, all birds will move from random position and random velocities. After some time, all birds will follow the path of the bird nearest to the food after considering each other's flying experience. In PSO we define a fitness function which is to be optimized. With each iteration two best solutions of the fitness values are found; one is 'pbest', the best fitness value a particle (bird) has reached and second is 'gbest', the best fitness value achieved by any particle (bird) in the population so far[21]. The flow chart of PSO is as shown in figure1.

Each particles velocity and position are updated by the following equations (7) and (8):

$$v_{i+1} = w*v_i + c_1*rnd_1*(pbest_i - x_i) + c_2*rnd_2*(gbest_i - x_i) \tag{7}$$

$$x_{i+1} = x_i + v_i \tag{8}$$

where i denotes the iteration number, w is the initial weight, c_1 and c_2 are the cognitive (particle's own) and social (collaboration among particles) scaling parameters which are positive constants (here c_1 is 2.5 and c_2 is 1.5) and rnd_1 and rnd_2 are two random values in the range [0,1]. In present work, the PSO algorithm is applied to estimate the value of reflection coefficient s_{11} for dipole and loop antenna as considered in [12] with respect to the distance parameter D for the antennas used in WBAN applications. PSO algorithm was executed using matlab with a population size of 20 and 500 iterations. The fitness function FF_1 for estimation of s_{11} is as mentioned in equation (9) and fitness function FF_2 for SAR is mentioned in equation (10) :

$$FF_1 = \sum_{k=1}^{N} a_k S_{11k} - \sum_{l=1}^{N} b_l S_{11l} \tag{9}$$

$$FF_2 = \sum_{k=1}^{N} a_k SAR_k - \sum_{l=1}^{N} b_l SAR_l \tag{10}$$

Where a_k and b_l are the weights that control the contribution from calculated value and simulated value respectively each term to the overall fitness function. The constant N represents the number of points of measurement, for our problem the point of measurement are 7 ie at a distance of 0mm, 2mm, 8mm,12mm,18mm,30mm and free space. In our analysis, we take the weights a_k = 1 and b_l = 1.

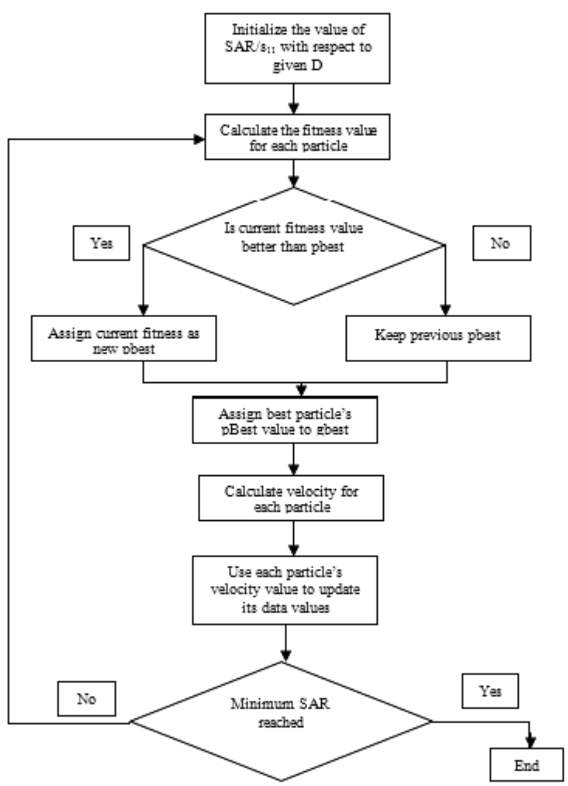

Figure 1: PSO Algorithm Flow Chart

6. RESULTS AND DISCUSSIONS.

Since the wearable sensor antennas are placed in close proximity of the human body, we have calculated the optimized values of SAR and s_{11} with respect to the antenna-human body distances (D).

In [12], for the values of D (in mm) as 0, 2, 8, 12, 18, 30 and free space the reflection coefficient $S_{11,}$ has been measured practically. In our paper, the comparison of practically measured, simulated and estimated values of s_{11} using PSO algorithm, for WBAN antenna operating at 2.4 GHz frequency are presented. The simulation of the on-body antenna for SAR evaluations are also carried using CST (computer simulation tool) microwave studio.

Table 1
On-body Antenna Distance to the Reflection Coefficient

	S_{11} *for dipole antenna type WBAN antenna*			S_{11} *for loop antenna type WBAN antenna*		
D(mm)	*measured*	*Simulated*	*Estimated using PSO*	*Measured*	*Simulated*	*Estimated using PSO*
0	-15.25	-11.52	-10.25	-8.31	-12.23	-8.01
2	-4.99	-7.66	-4.26	-10.23	-27.36	-8.05
8	-2.63	-5.98	-2.87	-10.21	-15.39	-8.03
12	-2.45	-4.87	-2.34	-10.01	-11.23	-8.16
18	-1.75	-4.25	-1.25	-5.38	-10.18	-5.02
30	-1.63	-4.56	-1.21	-2.81	-2.13	-2.01
Free space	-1.52	-1.89	-1.01	-2.10	-2.01	-1.89

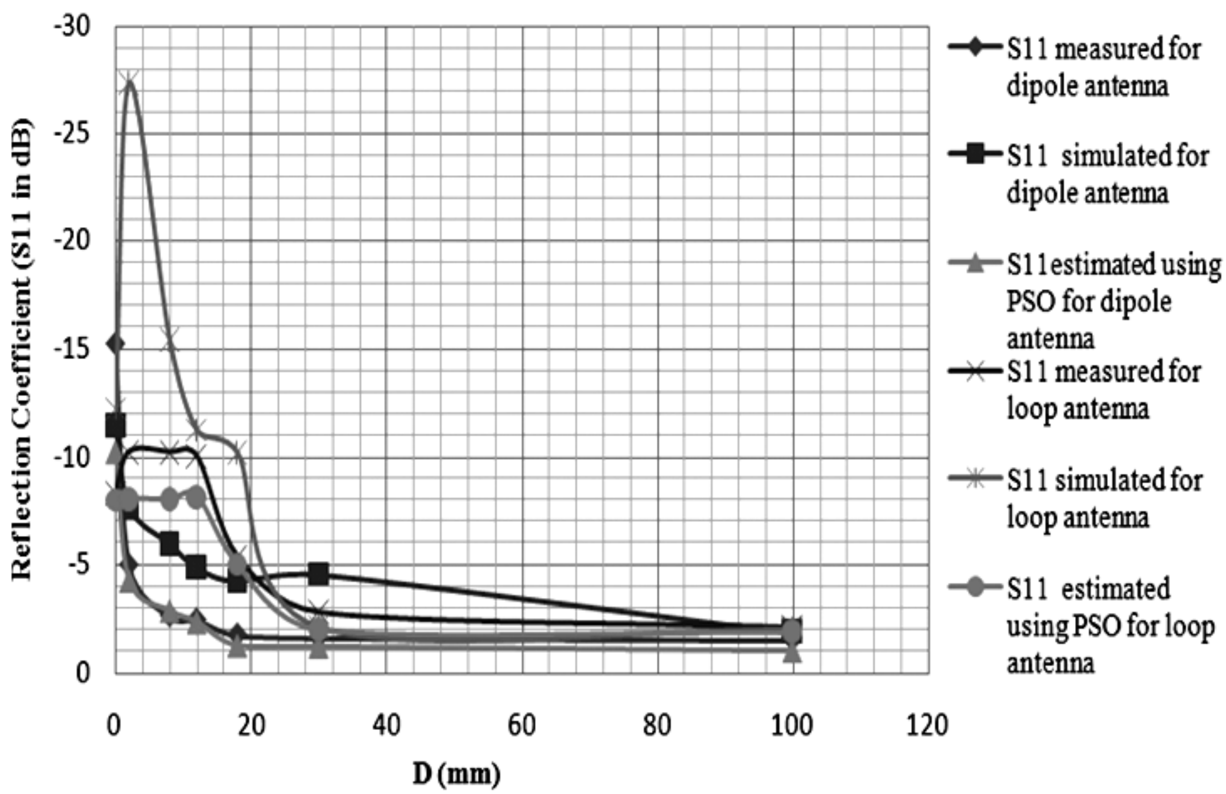

Figure 2: On-body Antenna Distance to the Reflection Coefficient Graph

Table 1 and Figure 2, shows that as the distance of the antenna increases from the human body the reflection coefficients gets improved, there is lesser attenuation. The results are showing sudden sharp improvement when the distance is changed to 18mm from 12mm and further improves drastically when distance is increased to 30mm. when the results for the reflection coefficient are measured for free space it doesn't show much improvement in reflection coefficient compared to the transition of 12mm to 30 mm. therefore we can conclude that the wearable WBAN antennas behaves well when kept at a distance of 12mm to 30mm rather than to stick to the body or keeping much away from the body.

Table 2
On-body Antenna Distance to the SAR values

	dipole antenna type WBAN antenna			*loop antenna type WBAN antenna*		
D(mm)	*SAR measured*	*Simulated SAR*	*SAR estimated using PSO*	*SAR measured*	*Simulated SAR*	*SAR estimated using PSO*
0	0.467	0.426	0.392	0.865	0.922	0.741
2	0.423	0.413	0.351	0.794	0.856	0.673
8	0.389	0.398	0.326	0.623	0.741	0.581
12	0.274	0.256	0.224	0.581	0.824	0.555
18	0.235	0.183	0.163	0.553	0.535	0.482
30	0.159	0.121	0.091	0.412	0.337	0.331
Free space	0.028	0.053	0.012	0.091	0.153	0.071

The SAR values for the assumed setup [12] were calculated using CST simulator. These results were further estimated using PSO algorithm. As shown in Table 2 and Figure 3, the SAR results also support the s_{11} results.

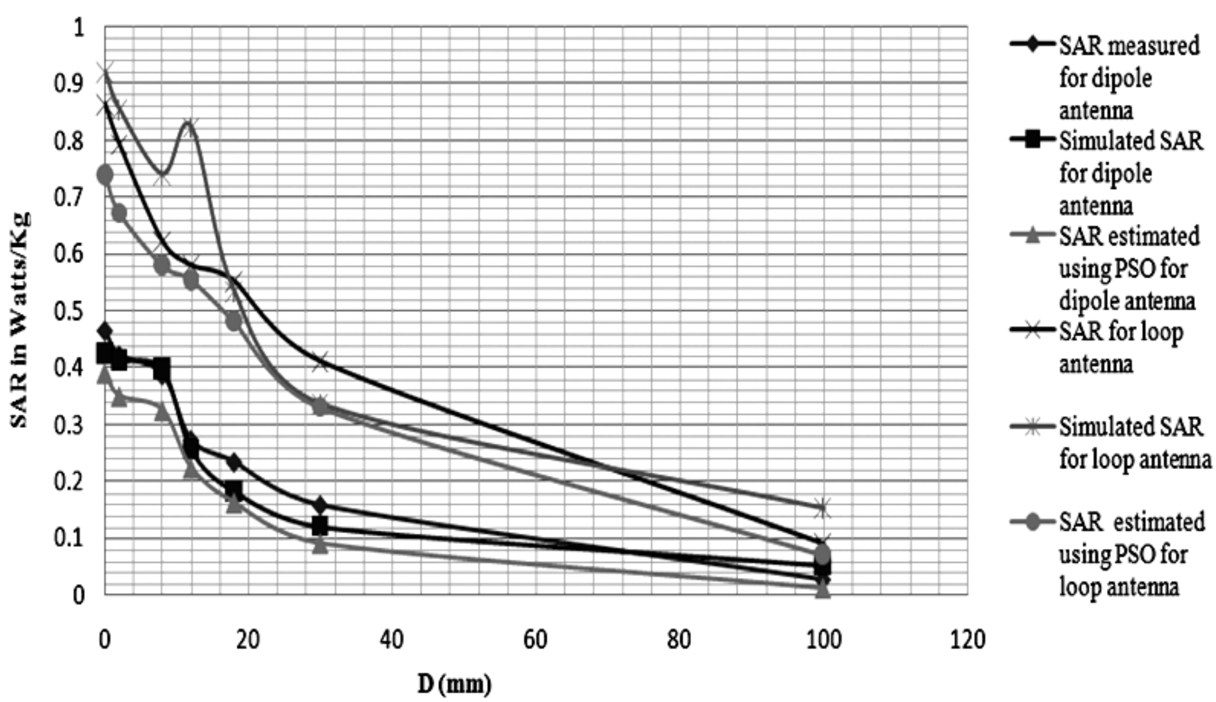

Figure 3: On-body Antenna Distance to the SAR values Graph

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