Specific Absorption Rates in the Human Head and Shoulder for Passive UHF RFID Systems at 915 MHz

Darmindra D. Arumugam[1], Daniel W. Engels[2]

[1, 2]University of Texas at Arlington
416 Yates Street, Arlington, TX 76010
[1]darumugam@uta.edu
[2]dengels@uta.edu

Abstract

In this paper, we use a human head and shoulder model to extend the theory and analysis of specific absorption rates (SAR) in the human head due to radiation caused by passive radio frequency identification (RFID) reader systems. We use a finite-element method (FEM), and a human head and shoulder model with a voxel size of 8mm for the tetrahedral to analyze the peak one-voxel SAR, spatial-peak 1g cube of tissue SAR, spatial-peak 10g cube of tissue SAR, and the average SAR in the human head. We present analytical evaluations to study the SAR in the human head at 1W radiated power output of a 7.4dB gain RFID reader patch antenna at distances of 10cm, 100cm and 1000cm from the front of the human head, at the cut-plane intersection of the human eye. We also show that in an ideal absorption environment, an RFID reader at 10cm from the human head presents a SAR above 1.6W/kg for both the spatial-peak 1g and 10g cube of tissue, the maximum value allowed by the Federal Communications Commission (FCC) in the US.

1. Introduction

The advent of advanced wireless systems recently has begun to create seamless interconnectivity between the human species through excellence in communications. These advances bring various positive advantages to society, but also impact human beings in numerous ways. One form of intervention with the human body is the propagation of radio frequency (RF) waves through biological tissues within the human body. Propagation of electric fields in the human body and biological tissues has previously been studied extensively for localized radiation sources such as cellular telephones. Absorption of RF energy by tissues and the human body is typically used to study both short term and long term impacts caused to the human body, but have previously not been studied in detail for other emerging wireless systems.

This paper is organized as follows: a discussion on related work is presented in Section 2 to enumerate previous work and to survey the existing literature. Section 3 presents the analytical test setup as well as the simulation environment used in this paper. Section 4 presents the electric field, magnetic field, and SAR of the near field ortho-slices of interest in the human head. In this section, we acquire data from the SAR cross-sectional results and present an analysis of SAR in a 3-dimensional human head. Here, quantitative results are used to evaluate the occurrences of high risk exposures in parts of the human head and shoulders.

2. Related Work

Anatomical studies of the human body have been researched for many decades in an attempt to understand the occurrence of high risk occurrences due to RF radiation on the human body. Most of the previous work have utilized magnetic resonance imaging (MRI) and computed tomography (CT) scan techniques to understand the positioning and properties of human tissues. The data collected from these techniques have been used previously to build models of the human body, both mathematical and phantom like. Both the MRI and CT scan techniques provide transverse slices or segmentations of the human body that were then used as parameters to the model developed. MRI data are generally much higher in resolution than the CT scan, and in most instances are very successful at distinguishing interior tissues [1]. The clear drawback of the MRI method is the time consumption [1] that is required to first acquire data from each transverse slice and then convert the data through data capture and automated modeling techniques in some instances. Nevertheless, these methods have become the key to understanding the placement of tissues within the human bodies and their properties. Segmentation is the process at which the information from these techniques is used to develop a numerical dosimetric model which would be mathematically solvable. The two well known mathematical models used are the finite-difference time-domain (FDTD) method and the finite-element method (FEM). Even with the processing capacity and intelligence of automation methods and computers today, the process of segmentation is still very hard to automate, and in most instances can be accomplished quicker through manual segmentation.

Figure 1 depicts the three major models that have been previously reported to be successful in characterizing the SAR in the human body. Wang and Fujiwara [2] developed a numerical model of a human head (Figure 1a) consisting of 17 different tissues, and a voxel size of 2 × 2 × 2 mm in 2002. This model is composed of more than 520,000 cubic voxels, with a voxel volume of 8 mm^2, where each volume was assigned to a specific type of tissue [1]. This method has previously been shown to be accurate only for localized sources of radiation since the rest of the human body cannot play a role in absorption. As we already know [3], absorption using non-localized systems is more accurate when there are bigger parts of the biological system in consideration, in this case a larger part of the human body.

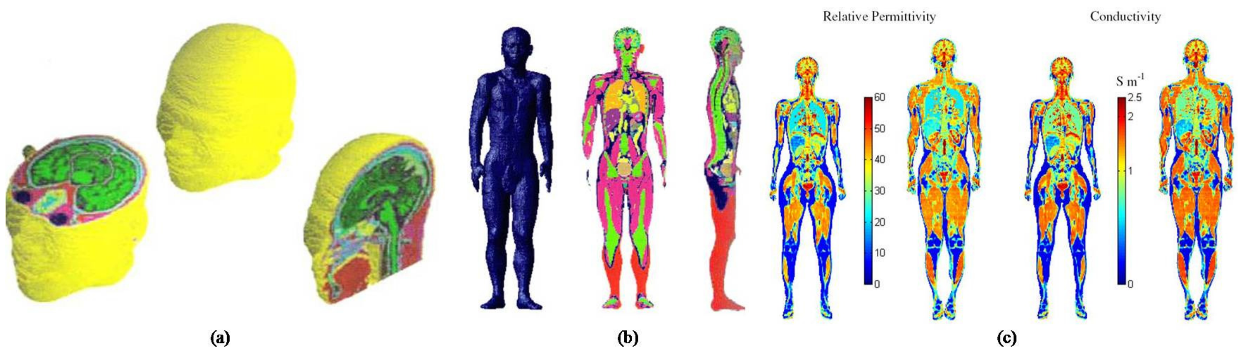

Figure 1: Anatomical models of the human body using MRI: (a) Human head model [2]; (b) Whole body model of an adult Japanese male [4]; (c) Continues model using grayscale semi-automatic extraction [5]

Nagaoka et al. [4] developed a numerical model based on MRI data of a whole body adult male, consisting of 51 tissue types and a voxel size of 2 × 2 × 2 mm in 2004 (Figure 1b). Completion of this model required three full years [1, 4], and has a resolution of 2 mm, and a voxel volume of 8 mm^2. This model is very accurate and considerably complete and complex, but has yet to be use for studies pertaining to passive RFID systems in dense environments. Sandrini et al. [5] published a method that is resource friendly, which completely ignored the use of voxels. This method disregarded the voxel method and allows for data extraction from grayscales in the MRI data, which provide for semi-automatic generation of the dielectric model [1, 5]. The results of this experiment depicted in Figure 1c show that a dielectric anatomical model can be used to generalize the exposure to RF radiation from the far field [1, 5]. This generalized model requires the use of continues transfer function during extraction from MRI grayscales, and therefore do not allow for the discretization of organs within the human body [1]. This makes SAR incalculable throughout the entire body accurately, and definitely incalculable for specific organs or tissues.

3. Simulation Environment and Analytical Test Setup

The analytical analysis is conducted in an electromagnetic environment called Feko, which is developed using leading computational electromagnetic (CEM) methods. The method used here is the hybrid MoM/FEM which involves the full coupling using MoM methods with the heterogeneous dielectric bodies in the FEM regions. This method is accurate for the structure sizes used in this paper. The human head and shoulder model is an inhomogeneous model containing 300,000 8 mm size tetrahedrals, and can be solved on a 32-bit machine with 2GByte of RAM. The model is meshed to be accurate for usage or operation up to 1 GHz, and the medium properties for the 25 tissues incorporated in this model are derived from FCC for 915 MHz [6]. The analysis is conducted using the setup displayed in Figure 2a. A square patch antenna is designed with a width and length of a quarter wavelengths to radiate up to 7.4dB gain in free space. This antenna is designed to utilize air as the dielectric medium between the patch and the ground plane, and a feed pin is used to supply a source port. The port is placed in the middle of the feed pin, and is used as a radiation point source with a 1V source magnitude at a phase of 0°. The radiation is conducted using a total source power of 1W, and the mesh size for the antenna is 20 times smaller than wavelength of the maximum frequency of passive UHF RFID systems in US (928 MHz) as allowed by FCC. In total, there were 45 segments for the feed pin and 600 FEM triangles for the patch (and metal back-plane) in the mesh for the antenna design. The human head and shoulder model is meshed using the values provided in [6], and near field values are calculated at an increment of 1mm in the x, y, and z axis for the electric field, magnetic field, pointing vector, and SAR values. The patch antenna is always located on the y-axis and is varied in distances from the human head. The simulations are conducted for the cases where the patch antenna is located at 10cm, 100cm, and 1000cm from the human head on the +y-axis.

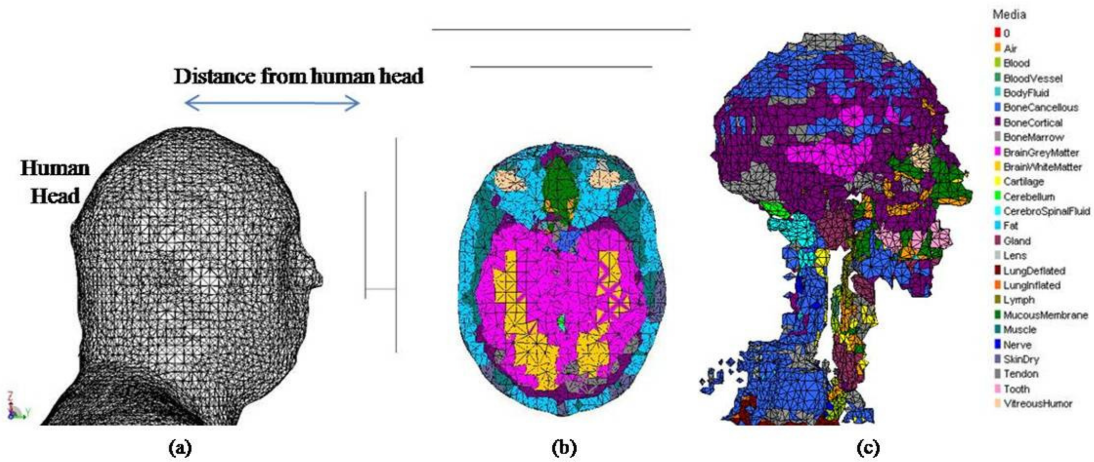

Figure 2: Human head and shoulder model used for the purpose of the numerical analysis: (a) Test setup for the 7.4dB gain RFID reader antenna; (b) Composition of tissues in the cut-plane of interest in the human head; (c) Composition of tissues in the 3D model without the fat, muscle an skin

Figure 2b depicts the cut-plane where the near field calculations are conducted to study the 2D components of the electric field, magnetic field, pointing vector, and SAR. Here we notice that the cut-plane is chosen to enable calculations at the intersection of the human eye. This is important because the cornea in the human eye contains non-regenerative human cells and cannot repair damages caused by radiation. This intersection is also chosen because the opening created by the human eye socket enables higher levels of radiation to seep through into the human head, and have previously been shown to increase the SAR within the head itself. Figure 2c depicts the entire human head and shoulder model with the corresponding mediums from the side and front view without the fat, muscle, and skin tissues.

4. Quantitative Analysis

The results of the analysis conducted using the setup as described in the previous section and the environment in Section 3 is best understood by analyzing the electric field, magnetic field, and SAR variations in the 2D cut-plane of interest. Figure 3 is a plot of the electric and magnetic near field as well as SAR calculations at the cut-plane of interest in the human head. If we look closely, we see that there does exist some level of transverse reaction between the two fields. Here we point out that the long term impacts of magnetic fields on the human body must be studied to relate the effect of fields on cells and its processes as well as functions.

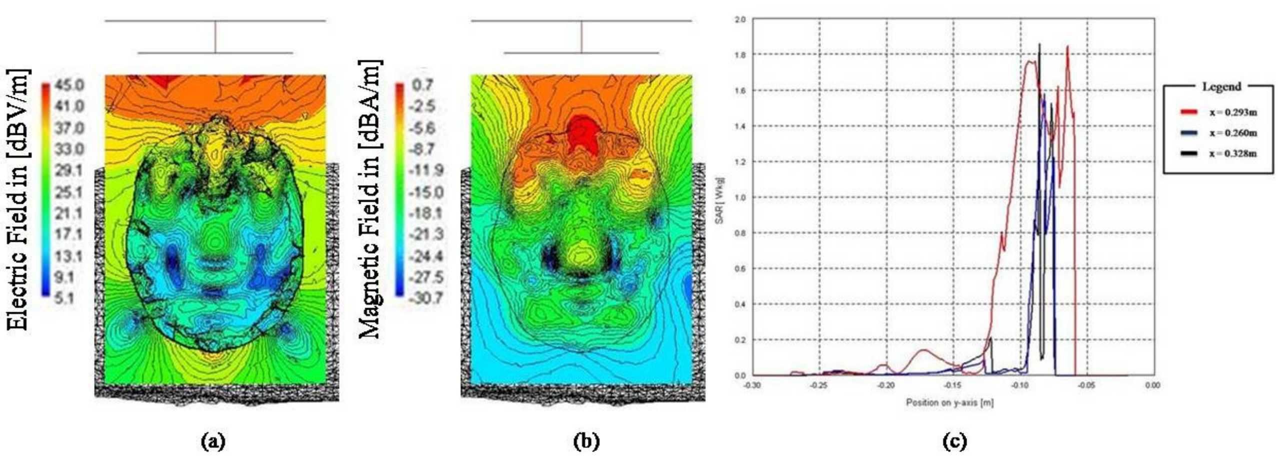

Figure 3: Field calculations at the cut-plane of interest (Figure 2b) for the: (a) Electric near field in dBV/m; (b) Magnetic near field in dBA/m; (c) SAR in W/kg at the line-of-sight at the left eye (red), right eye (black), and in between both eyes (blue); for the RFID reader antenna radiating 1W of power at 10cm away from the human head and shoulder model

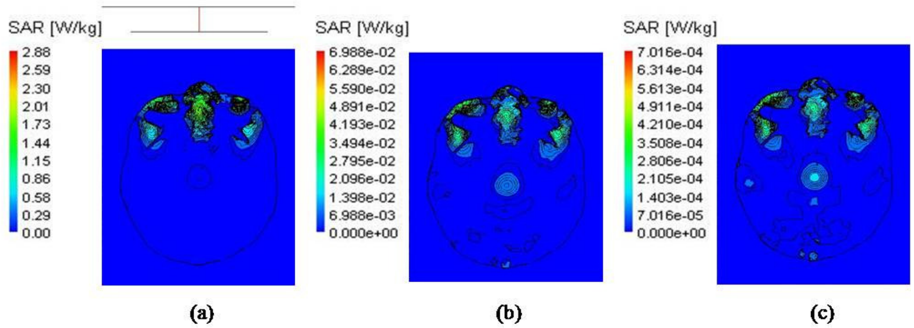

Figure 4: SAR for the 2D cut-plane of interest in the human head at distances of: (a) 10cm; (b) 100cm; (c) 1000cm; from the 7.4dB passive UHF RFID reader antenna

Figure 4 presents the SAR calculations for the 2-dimensional cut-plane studied for the three cases of distances from the human head. These cases are for the 7.4db gain RFID reader antenna at 10cm, 100cm, and 1000cm from the front of the human head, radiating at 1W. From these results, we notice that contrary to common knowledge, the SAR variation and gradients do not change drastically when the reader antenna is distanced away from the human head. However, the values of the peak-one voxel SAR values reduce drastically, when the reader antenna is moved away from the human head.

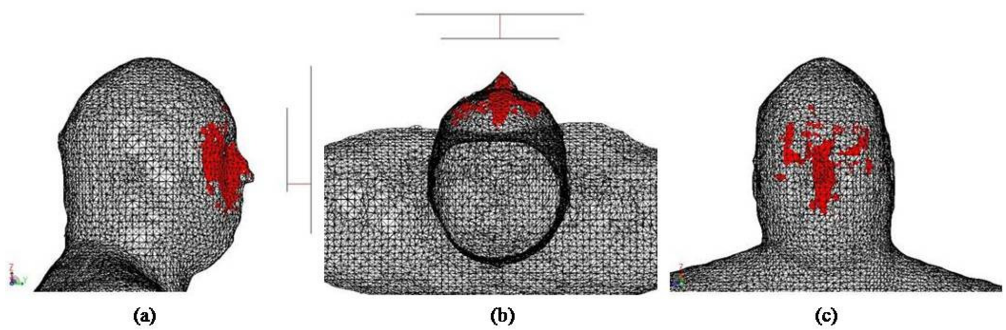

Figure 5: 3D iso-surfaces of the SAR calculations at 10cm from the human head and shoulder model at 1.6 W/kg from the: (a) side; (b) top; (c) front; view

Figure 5 presents the three dimensional SAR results for the human head using iso-surfaces with the RFID reader antenna at 10cm from the human head, radiating at 1W for the peak-one voxel SAR of 1.6 W/kg. Using this evidence, we conclude that there needs to be significant work contributed in this area to enable a higher understanding of the impact of RF radiation on the human head by RFID reader systems at UHF frequencies. We also conclude that these studies must focus both on the short term and long term impact on the human body, given the accelerated adoption rates of passive RFID systems today.

5. References

1. M. Kato, "Electromagnetics in Biology," *Springer*, Hicom, Japan: CRC, ch. 9, pp. 221-250, 2006.
2. O. P. Gandhi, J. Y. Chen and D. Wu. "Electromagnetic absorption in the human head for mobile telephones at 835 and 1900 MHz," *Proc. Int. Symp. Electromag. Compat.*, (EMC'94 Roma), Sept. 13-16, 1994.
3. O. P. Gandhi, L. Gianluca and C. Furse, "Electromagnetic Absorption in the Human Head and Neck for Mobile Telephones at 835 and 1900 MHz," *IEEE Trans. on MTT*, vol. 44, pp. 1884-1897, 1996.
4. T. Nagaoka, S. Watanabe, K. Saurai, E. Kunieda, S. Watanabe, M. Taki and Y. Yamanaka, "Development of realistic high-resolution whole-body voxel models of Japanese adult males and females of average height and weight, and application of models to radio-frequency electromagnetic-field dosimetry," *Phys. Med. Biol.*, vol. 49, pp. 1-15, 2004.
5. L. Sandrini, A. Vaccari, C. Malacarne, L. Cristoforetti and R. Pontalti, "RF dosimetry: a comparison between power absorption of female and male numerical models from 0.1 to 4 GHz," *Phys. Med. Biol..*, vol. 49, pp. 5185-5201, 2004.
6. FCC, *Tissue Dielectric Properties, 915 MHz*, http://www.fcc.gov/cgi-bin/dielec.sh