Efficient procedures in assessment of incident power density on non-planar tissue models under electromagnetic exposure in mmWave spectrum

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***Abstract*—Given that the 5^{th} generation mobile communication technology (5G) is currently being actively deployed worldwide, international guidelines and standards for human exposure to radiated electromagnetic fields have been revised. Entering the mmWave frequency range, incident (or epithelial) power density is adopted as the new dosimetric reference level. However, most of the researchers still use classical and outdated techniques that rely heavily on finite difference schemes which introduce rough approximations of human tissue geometry, and thus lose the mathematical rigor of the formulation and do not acquire physical interpretability of the final result. This paper aims to present threefold progress to current efforts in assessment of incident power density: (i) use of non-planar, multi-layer models of human tissue; (ii) application of realistic exposure scenarios; (iii) faster and more accurate computation supported by modern data-driven techniques.**

***Index Terms*—computational dosimetry, incident power density, 5G communication technology**

I. Introduction

Due to the increase in the number of smart personal mobile devices and the consequent need for greater network capacity and reliability, the 5^{th} generation mobile communication technology (5G) utilizes mmWave frequency spectrum. As biological effects of radiation in ultra and super high frequency bands of radio spectrum, 3 GHz to 30 GHz and 30 GHz to 300 GHz, respectively, have been scarcely investigated, the international guidelines [1] for human protection from electromagnetic fields have been revised, focusing on frequencies above the transition frequency of 6 GHz. For such high frequencies, the effect of radiation is substantial on the surface and negligible elsewhere throughout the tissue. Therefore, novel dosimetric reference level for human exposure has been determined as the incident power density (IPD). IPD is a free space approximation of the absorbed power density averaged over an irradiated area of tissue, A, of either 1 cm^2 or 4 cm^2, corresponding to the area of the exposed surface of 1 g or 10 g cube of tissue, respectively [2]. It is defined as the surface integral of the real part of the magnitude of the Poynting vector, $\vec{S}$, as follows:

$$S_{ab} = \frac{1}{2A} \iint_A \Re[\vec{S}] d\vec{s} \tag{1}$$

where $\vec{S} = \vec{E} \times \vec{H}^*$ and yields a direction of the electromagnetic wave propagation.

More than ever, simulations of human exposure have to be executed with high numerical accuracy, and within more realistic exposure scenarios. This paper summarizes current efforts on potential improvements in relation to the overall computational dosimetry research for human exposure to radio-frequency electromagnetic waves conducted so far [3], focusing on near-field conditions.

II. Improvements in the assessment of the IPD

A. Realistic sources of radiated electromagnetic fields

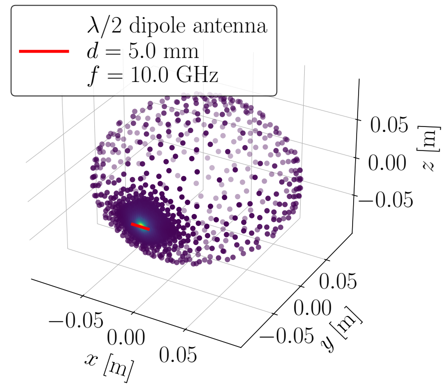
Human exposure simulations are conducted by placing a center-fed half-wave dipole as a realistic source of radiated electromagnetic fields in the immediate vicinity of the model of human head. Current distribution along the dipole is governed by the Pocklington integro-differential equation, and the solution is carried out by means of Galerkin-Bubnov scheme of the indirect boundary element method. It is then straightforward to obtain electric and magnetic field equations from the boundary element formalism itself [4].

B. Application of automatic differentiation

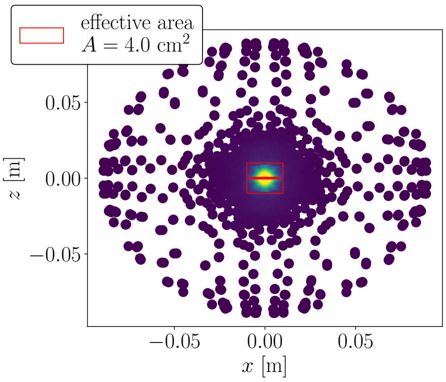
Automatic differentiation (AD) is a set of techniques in which a numeric computer program can be differentiated algorithmically to machine precision without producing round-off and truncation errors [5]. AD is ubiquitous in many computational sciences, notably machine learning, but still underutilized in the area of computational dosimetry and computational electromagnetism in general. Thanks to the renaissance in the development of AD-powered libraries, authors in [6] showcase seamless implementation of AD in the assessment of the IPD with some illustrative examples. AD has been proven superior over numerical differentiation by means of the computation speed and accuracy.

C. Realistic human models

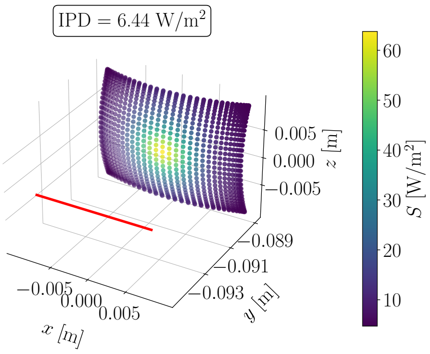
Non-planar geometries, either spherical as in figs. 1a and 1b or realistic as in figs. 2a and 2b, require the use of a surface integration of vector field in order to obtain the solution of eq. (1). For spherical models, one can perform a Gaussian quadrature tailored to a specific geometry by converting the Cartesian representation of point cloud to spherical coordinates, demonstrated in fig. 1c. For realistic models, analytical



(a) 3-D point cloud defines the surface of the spherical model of human head.

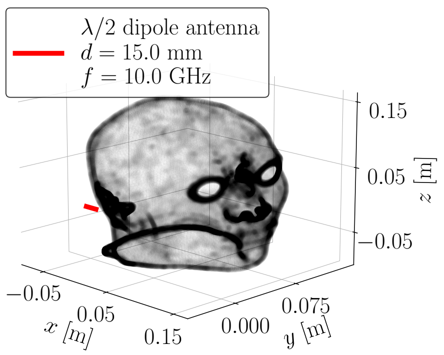


(b) 2-D point cloud in xz plane.

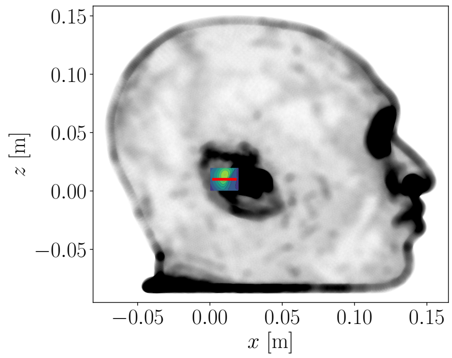


(c) Effective irradiated area of the surface, w.r.t. which the IPD is computed by using the Gaussian quadrature adapted to handle surface integrals.

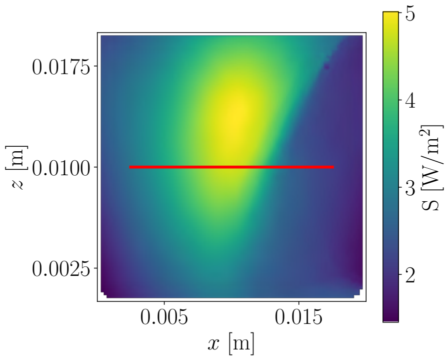
Fig. 1: Power density distribution over a 3-D spherical, homogeneous model of human head, which diametrically extends to 18 cm. Half-wave dipole, set to operating frequency of 10 GHz, is located at a distance of 5 mm from the averaging area.



(a) Geometry of the common exposure scenario while using a personal mobile device.



(b) 2-D view from the perspective of a personal mobile device.



(c) Effective irradiated area of the surface, w.r.t. which the IPD needs to be computed.

Fig. 2: Power density distribution over a 3-D realistic model of human head. Averaging area, A, equals to 4 cm^2, distance between the half-wave dipole and the averaging area, d, is 15 mm, and operating frequency of the dipole, f, is set to 10 GHz.

definition of the integral variable vector, $d\vec{s}$, is unfeasible. The parametrization of such averaging surfaces will have to be performed via physics-informed neural networks [7], where the y axis could be expressed as the functional of x and z axes, fig. 2c. This extends into future research work.

III. Concluding Remarks

This paper provides a concise overview of the research conducted to improve the computation speed and numerical accuracy of simulations of human exposure to radiated electromagnetic fields through the incident power density. Future work will deal with the numerical evaluation of the incident power density on extremely irregular surfaces, e.g., exposed regions of human head, where common quadrature techniques cannot be applied effectively.

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