A Dynamic Human Body Computational Phantom for RF Propagation Study

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***Abstract*—Recent advances in micro-electronics technology to build small radio-enabled implantable and wearable medical sensors have sparked considerable interest in further understanding the characteristics of radio frequency propagation inside the human body. As physical experiment with human subjects is either difficult or in some cases impossible to carry out, computational phantoms offer an attractive alternative for researchers in this area. However, computational phantoms used in the literature to study such propagation characteristics are mostly static. As body motion could significantly impact the wireless communication between implants and wearable medical sensors, a dynamic computational phantom capable of emulating human motion would be a valuable tool to study and understand this impact. Here, we describe the development of a dynamic posable computational phantom for the full human body. This enhanced phantom will be used to study dynamic implant channels in a network consisting of implants and wearable sensors. Our methodology and tools along with problems encountered and their solutions are briefly discussed in this paper.**

***Index Terms*—radio frequency propagation; 3D immersive platform; computational phantom**

I. INTRODUCTION

Recent advances in microelectronics indicate that the technology to achieve ultra-small and ultra-low power implantable and wearable devices is closer to becoming a reality. Successful adoption of these devices heavily depends on the existence of a global standard for their wireless communication link. Factors such as interference and co-existence with other wireless technologies will also impact the reliability and usability of such devices for medical application.

Efficient transceiver design for implants or wearable devices requires in-depth understanding of the propagation media i.e. the human body. Due to the difficulties of performing experiments with human subjects, obtaining sufficient amounts of measurement data for such use-cases is extremely difficult or in some cases nearly impossible. Therefore computational phantoms specialized for RF studies will be a valuable tool to conduct virtual experiments and obtain important information related to RF propagation inside the human body. In our laboratory, we have developed an immersive environment that allows 3D data visualization and interaction with a virtual human body (see Fig. 1). The 3D body model used in the experiments includes frequency dependent dielectric properties of 300+ parts of a male human body. These properties are also user-definable if custom changes or modifications are desired. The human body model has a resolution of 2 mm.

Using our immersive platform, a researcher is able to place a customized antenna at the desired location of the human body and study the RF propagation at the target frequency for a variety of scenarios or medical applications [1,2,3]. However, the static nature of the body model used in these types of research does not allow capturing realistic variations of RF propagation from implants in more realistic scenarios where human motion is involved. Lack of a reliable communication channel in a dynamic environment has been shown by authors in [4] through limited physical measurements.

As body motion could significantly impact the wireless communication between implants and wearable medical sensors, a dynamic computational phantom capable of emulating human motion would be a valuable tool to study and understand this impact. Our objective in this work is to create a dynamic computational phantom as an extension to the existing static body model. The dynamic phantom would be capable of emulating human motion such as walking, rolling in a bed, twisting/turning, and bending.

Figure 1. A user in the NIST immersive visualization environment interacting with the 3D computational phantom

II. IMPLEMENTATION OF THE DYMAMIC HUMAN BODY MODEL

A. *Methodology to Create Body Motion*

Our method for creating a dynamic human body model is to modify the static model using existing software to create various pose sequences; and then to move the posed phantoms back into the simulation platform. Custom codes have been developed to facilitate this process.

Blender[1] (i.e. a 3D animation software) has been used as the primary tool for creating pose sequences from the static body model geometry. Motion of the body model (e.g. walking) is generated by a series of still poses; similar to the image frames in a motion picture. Blender was chosen due to its ability to import/export geometric models in a variety of formats, as well as its flexible animation capabilities. Blender enables us to manipulate the position of the static human body model by creating an *armature* and attaching the static model's surface meshes to that armature. The armature is a simplified skeletal representation of the movable parts of the body. The armature can then be manipulated and poses of the armature generate poses of the attached surface meshes. Movements (such as a walking) are generated by the use of *keyframes*. Keyframes specify poses at specific points in time. Intermediate poses are then generated by interpolation between the keyframes. Following this strategy, a series of poses has been generated and exported from Blender. These posed meshes have then been imported into HFSS[1] for the corresponding RF propagation simulations.

Both HFSS and Blender are primarily used through a graphical user interface; however, scripts written by the user can control both programs. Extensive use of these scripting capabilities enabled us to automate the repetitive procedures required for the creation and use of the pose sequences. Additionally, we have developed custom codes for conversion of data formats and for combining the modified meshes to create complete body phantoms for each pose.

B. *Technical Challenges*

Moving the static body model meshes into Blender proved to be straightforward however it was important to completely represent the mesh connectivity given to Blender. If this is not done properly, Blender might produce posed meshes that have gaps. In this work, both VRML and OBJ file formats have been used for moving mesh data between Blender and HFSS. The posed models were imported back into HFSS by processing the OBJ files generated by Blender to produce HFSS scripts; these scripts built the posed meshes within HFSS.

Another challenge to overcome was the proper assignment of dielectric properties to the imported meshes when moving the posed models back into HFSS. This was done by the simple expedient of using file names for each posed boundary mesh that identified the represented structure. The Blender scripting methods make this process reasonably straightforward. HFSS scripts were then developed to use these naming conventions to reattach the proper dielectric properties to the imported posed meshes.

Another important technical issue to resolve was Blender's potential distortion of the posed meshes into shapes that were either unrealistic or caused intersections. If this happens, the mesh structure becomes unusable within HFSS. This might occur because Blender is a tool mainly used for generating 3D animations for entertainment. It is not intended to produce results that are physically valid for scientific analysis. The most serious of these problems arose when a posed mesh intersected itself or when two meshes from the same pose intersected one another. When such intersections occur, HFSS will not be able to perform any RF propagation simulation.

To detect such intersections, we used MeshLab[1] to analyze the output of Blender (i.e. the OBJ files) and report these intersections. MeshLab is open source tool that can perform a variety of analyses and operations on meshes. The identified intersections were then resolved by going back into Blender and manually making small adjustments to the shapes of the meshes and their attachments to the controlling armature.

Although this process was very labor-intensive, we found it to be the most effective way of eliminating mesh intersections. Exploiting other features of Blender to address the intersection problem proved to be unsuccessful. For example, Blender has several "simulation" features, such as the *soft body* and *cloth* that are intended (in part) to handle the intersection problem. These features did not eliminate mesh intersections and in some cases they caused undesirable geometric distortions.

An alternative method to handle the mesh intersection problem would be to use the Boolean mesh operations within HFSS. This method requires importing the intersecting meshes into HFSS, and then using the Boolean mesh operations to eliminate the intersecting region from one of the meshes. This approach could be automated by using HFSS scripts created from the results of the MeshLab analysis; resulting in a much less labor-intensive process. However, this method was not used because it has the potential to cause the elimination of important features from the smaller structures of the posed body model.

III. RESULTS

The sequence of posed models produced from the above methodology has been successfully imported into HFSS. One such sequence emulates a walking motion. This will allow us to study RF propagation from implants and/or other wearable medical sensors while the body is in this type of motion. It should be noted that the posed meshes are not necessarily anatomically correct representations of the shapes of the corresponding structures in an actual posed human. The changes that Blender causes in the shape of internal organs (such as the lungs or the heart) in the posed model may not be fully accurate; however, for the purposes of our RF simulations, we believe that they serve as reasonable representations. Figure 2 shows an example of our dynamic computational phantom forming a pose sequence that describes a walking motion. We plan to perform extensive studies on the wireless propagation from implants using our dynamic computational phantom. Those results will be available in future publications.

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[1] Blender is free open-source software maintained by the Blender Foundation (http://www.blender.org). HFSS is registered trademark of ANSYS Corporation. MeshLab is free open-source software supported by the 3D-COFORM consortium (http://www.3d-coform.eu). Blender, HFSS and MeshLab have been used in this research to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standard and Technology, nor does it imply that this product is necessarily the best available for the purpose.

Figure 2. A sample seqeunce of poses emulating a human walking motion

IV. CONCLUSION

The technology for networking various medical implants and body sensors is rapidly evolving with many novel applications. As these human body area networks are envisioned to be pervasively part of our daily life, the evaluation of their operational reliability has to be performed in more realistic scenarios. A dynamic computational phantom capable of emulating human motion will allow communication engineers to better study and understand the impact of motion on the quality of wireless links in these networks. The authors plan to use the dynamic computational phantom to do this study and provide the results in future publications.

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