Development of a Human Body Phantom Model for Wireless Body Area Network Applications

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Abstract — **Human body motions can have a significant impact on on-body electromagnetic (EM) wave propagations and affect wireless body area network (WBAN) applications. To help understand the body motion effects, an arm-swinging phantom model of the human upper body is developed in both measurement and simulation. The phantom model performance is compared to human volunteer results and shows similar time-varying behaviors.**

Index Terms – **Numerical simulation, wireless propagations, channel modeling, human body phantom model, body area network**

I. INTRODUCTION

Wireless body area network (WBAN) technology has the potential to improve human quality of life through applications such as remote, long-term health monitoring [1]-[2]. A WBAN system in health monitoring could be implemented as a series of wearable sensors, such as a heart rate monitor, blood pressure sensor, or motion sensor. These sensors would transmit data wirelessly to a body-worn control unit such as a smartphone. The control unit or smartphone app would collect the sensor data and relay it wirelessly over the internet to an outside medical facility, which can monitor the data to detect and respond to any impending medical emergencies. Implementing a practical WBAN system requires miniaturized, power-efficient antennas that allow for long-term operability of on-body sensors, and that minimize interference with activities of daily life while the sensors are worn.

Designing electrically small and power efficient antennas for such a WBAN system requires a thorough understanding of on-body EM wave propagation mechanisms, which can be significantly impacted by body motion [3]-[6]. Previous work has used a variety of approaches to study on-body wave propagation, including real human experiments, numerical simulation of human and computer models [4]-[6], and measurements using phantom models [7]-[8]

Experimental data collection methods provide valuable in-situ data related to on-body wave propagation; however, they are limited in scope because only data at the points of the transmitter and receiver can be collected, and they involve many uncontrollable factors such as body size and motion speed. Computer simulation methods allow for entire EM pathways between transmitting and receiving antennas to be analyzed and allow for more control over variables affecting on-body wave propagations. However, the computational demands of simulations can be time-consuming due to model complexity and resolution requirements. Using a phantom model in place of a real human body can allow for additional control over the body and motion parameters, and result in a large volume of measurement data in a shorter period of measurement time. In this study a phantom model is constructed, measured, and compared with human data to highlight how it can be used to study how body motion affects on-body wave propagations.

This paper is organized as follows. Section II describes the methods used for phantom creation, experimental data collection, and computer simulation. Section III shows a comparison of the phantom model in measurement and simulation with human volunteer data. Section IV details conclusions and future work.

II. METHODS

A. Phantom Creation and Experimental Data Collection

A human body phantom model is constructed out of plexiglass and is filled with tap water at room temperature (approximately 22°C), having a permittivity of 79.95 and a conductivity of 0.08. The phantom model is capable of arm swinging motions controlled by an Arduino and stepper motor system. The arm swings are programmed to be performed with a 3.0s cycle time.

Measurements are performed with the phantom model surrounded by ground absorbers, and while wearing two bridge monopole antennas in one of two antenna placement configurations: chest/left wrist (front) and both wrists (front), with front denoting the antenna is placed so the wrist monopole faces the same direction as the monopole on the chest when the arm is parallel to the torso, lengthwise. Measurements are performed at 433MHz. The antenna placements and frequencies can be easily changed.

A three-dimensional motion capture system from Vicon (Vicon Motion Systems Ltd., Oxford, United Kingdom) is time synchronized with a 2-port Agilent N5230C PNA-L vector network analyzer (VNA) to collect data at 120Hz. The phantom then performs a single arm swing motion while the motion capture system and VNA simultaneously capture body motion and antenna signal data, respectively. Fig. 1 shows the experimental setup for the phantom model.

Fig. 1. The phantom model of the human body performing an arm-swinging motion, while having motion capture markers and monopole antennas attached and surrounded by ground absorbers.

B. CST Modelling and Simulation

Computer simulation of the phantom model is performed in CST Microwave Studio 2017 (CST Computer Simulation Technology Gmbh, Darmstadt, Germany) to verify the phantom model's effectiveness in studying on-body EM wave propagation during motion. The computer model matches the size of the physically constructed phantom model and can be seen in Fig. 2. The computer model's arm motion is controlled to reproduce the measured motion capture data collected from the phantom model. A simulation technique is used whereby multiple consecutive time frames are simulated in sequence, each simulation representing a given instant of the motion activity. The sequence of simulations can thus reproduce an entire range of activity motion. Simulations are performed at 10 frames per second, which allows for the motion effects on S_{21} to be captured in the simulation. The time synchronization of the measured motion capture and antenna signal data allows for the simulated S_{21} to be compared directly in time with the measured S_{21}.

III. RESULTS

Comparison of the phantom model and human volunteer data is performed to validate the phantom model's accuracy. A Phasespace (Phasespace, Inc., San Leandro, California,

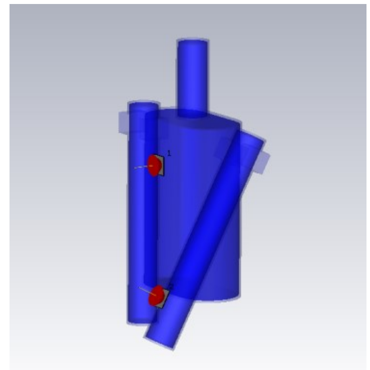

Fig. 2. Human body phantom model in CST with monopole antennas on the chest and left wrist (front).

United States) motion capture system is used to capture human volunteer motion in a setup similar to that of the phantom model, as seen in Fig. 3. Table I compares the dimensions of the phantom model and human volunteer. Normalized (shifted) data in Fig. 4 shows that both the phantom model and human volunteer exhibit a repeating S_{21} fluctuation pattern that have peaks and dips coinciding with various positions of the arm during the arm swing motion. The phantom measurement data is shifted by 1.97dB in Figure 4 and 1.67dB in Figure 5 so that the peak S_{21} values match in each plot.

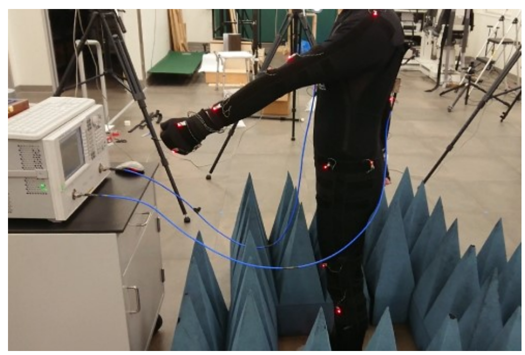

Fig. 3. A human volunteer performing an arm-swinging motion while wearing a motion capture bodysuit and monopole antennas and surrounded by ground absorbers.

TABLE I
PHANTOM AND HUMAN DIMENSIONS

	Phantom	Human
Torso Circumference (cm)	102.9	87.8
Torso Length (cm)	53.7	57
Arm Circumference (cm)	33	25.3
Arm Length (cm)	68.6	59

The results show that the simulation has generally good agreement with the measurement, as seen in normalized data in Fig. 5. Both simulation and measurement have a similar pattern, periodicity, and magnitude in terms of S_{21} over time during motion.

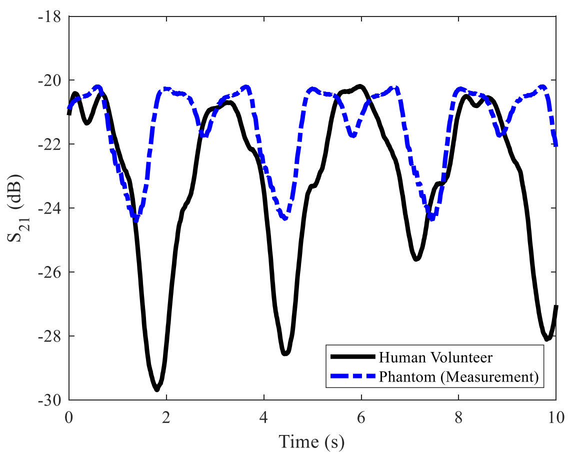

Fig. 4. Normalized S_{21} vs time for a single arm swing motion at 433MHz for the antenna on chest/left wrist (front) configuration. The plot shows a comparison of data from human volunteer measurement and phantom model measurement.

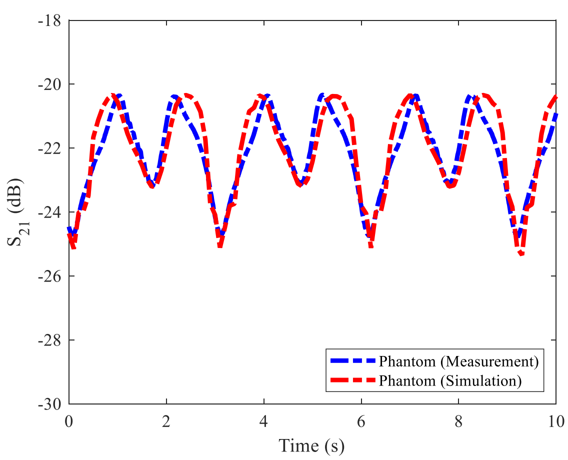

Fig. 5. Normalized S_{21} vs time for a single arm swing motion at 433MHz for the antenna on both wrists (front) configuration. The plot shows a comparison of data from phantom model measurement and phantom model simulation.

The largest discrepancies between human and phantom data occur during the dips in S_{21}, which correlate with the arm being behind the torso. This result suggests that non-line-of-sight scenarios may produce greater discrepancy in S_{21} magnitude between human and phantom data. However, the similarity of the repeating S_{21} fluctuation pattern over time in Fig. 4 shows that motion is affecting EM transmission between antennas for both the human and phantom model.

IV. Conclusions and Future Work

An arm-swinging human body phantom model has been constructed and tested in measurement and simulation. The phantom model was compared with measurement of a human volunteer. The phantom model has shown generally good agreement with the S_{21} fluctuation pattern caused by human motion demonstrated by the human volunteer data. The simulation model shows good agreement with the measured phantom model data.

The modular design of the phantom model allows for testing of various parameters affecting on-body wave propagation. Future work includes testing different tissue properties, body sizes, and motions using the phantom model, as well as testing various on-body antenna using the phantom model.

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