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A Study of Electromagnetic Wave Propagation for the Estimation of Human Density inside Rooms

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Abstract. In this paper a study on the estimation of human density in relation to the electromagnetic wave propagation distribution inside a room is shown. Due to the increasing use of portable wireless communication devices, man-made electromagnetic fields can be found almost everywhere people carry out activities. In particular areas, where high concentration of people exist, such as shopping malls, conference venues, sport halls, etc., it is possible to make use of electromagnetic field distribution variations in order to estimate the density of humans inside buildings. This research reflects recent studies trends in humans monitoring, both in position and movement. The work presented in this paper is the result of a statistical approach to the problem of relating electromagnetic propagation path losses with the density of humans inside a room. Following a strict methodology, therefore ensuring a complete repeatability of the studied model, experimental measurements have been carried out in order to confirm that human density levels inside a room can be predicted by using statistical models based on a proposed time domain EM simulated method.

Keywords: propagation, path loss, indoor wireless communication, human densities, human detection.

1. Introduction

During recent years the use of wireless mobile communication systems has grown fast among people. At the same time, in order to improve the performance of wireless communication systems, understanding of electromagnetic (EM) waves propagation characteristics inside rooms has been of fundamental importance. The performance of the wireless communication systems is greatly affected by the presence of people as well as other objects such as, for example, office furniture. Building wall structures and their outer shape affect the EM wave propagation characteristics, as it has been reported in recent studies conducted by the authors [1]. Other studies have shown how human presence in indoor spaces can also influence the EM wave propagation [2-4].

In this paper, EM waves propagating inside rooms are analyzed taking into account the presence of humans. The EM and experimental models mimic the humans as mainly constituted by a solution of water and a polymer contained in a dielectric cylinder. The EM waves are then attenuated and scattered similarly as by the human body.

This work focuses on two case studies. The first case deals with the room without humans inside. In the second case study, 25 humans are distributed inside the room in a cluster configuration occupying the right half side of the room. These two cases are first studied by means of 2D Finite Volume Time Domain computational method [5, 6]. The same EM model is then reproduced in a 2D experimental measurement system and results compared with the software predictions. These comparisons allow one to make predictions on the possible distribution of the humans inside the room, by monitoring the EM path losses.

The signal frequency used in this work is 10 GHz, which allows a convenient scaling of the experiment.

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2. Analytical Models of the Room and Humans

The geometrical model used for the EM FVTD simulations and as well as in the experimental measurement system is shown in Fig.1. The room is delimited by concrete walls whose thickness is T and the outer shape of the room is L_1 times W_3. Two doors of width W_4 are placed at the same side of the room. The overall room dimensions are parameterized in terms of the wavelength of the source used in this work. Final dimensions are listed in table 1.

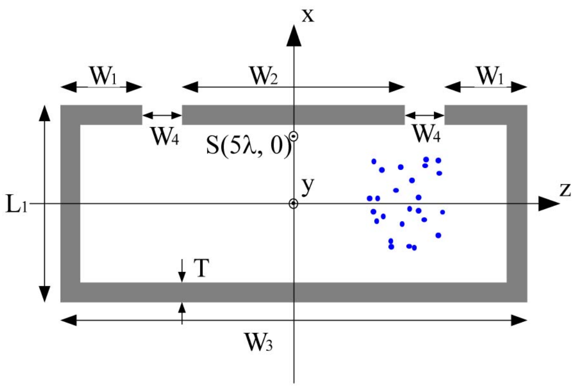

Fig. 1: Geometrical model of the room and human distribution used for the EM FVTD simulations and the experimental measurements. Humans are represented by blue dots.

As for the electrical properties of the human model and concrete wall, relative permittivity and conductivity are listed in table 2. As stated before, the human models are defined by a dielectric cylinder whose diameter is 2R.

The source location in the EM simulation and experimental model is located at $(x, z) = (5\lambda, 0)$ of Fig. 1. The origin of the co-ordinate system is located in the center of the room.

The distribution of humans studied in this paper reflects the one depicted in Fig.1, where the particular case of a cluster of 25 humans is set in the vicinity of the right side door.

Table 1: Parametric dimensions of the Room Model in Fig. 1. λ=30mm.

L_1	W_1	W_2	W_3	W_4	T
14.67λ	6.17λ	16.67λ	35.0λ	3.0λ	1.5λ

Table 2: Relative permittivity and conductivity of the Concrete and the Human Model in Fig. 1.

	Relative Permittivity ε_r	**Conductivity σ [S/m]**	**Size**
Concrete	5.0	0.1	T=1.5λ
Human Model	61.0	18.2	2R=0.33λ

3. Comparisons of Simulation and Measurement Results

The results shown in this section are the electric field strengths obtained by the FVTD method and experimentally measured by a probe antenna moving along the z axis shown in Fig. 1 from the left to the right side of the room walls.

In Fig. 2 the comparison between simulation and experimental data referring to the case of no humans inside the room shows how reliable the adopted FVDT method is in relation to the experimental measurements. This is also observed for the case of the cluster of 25 humans distributed in front of the right side door. In both cases fringes of the propagating field from the source point are observed at the left side of the z axis. Minimums of these fringes are clearly visible with natural symmetry for the case of no humans, Fig. 2. In Fig. 3 these fringes are visible at the left side of the plot similarly to the case of Fig. 2. This is due to the fact that for both cases there is no absorption due to human presence at z<0. Electric field strength is lower where humans presence causes energy absorption.

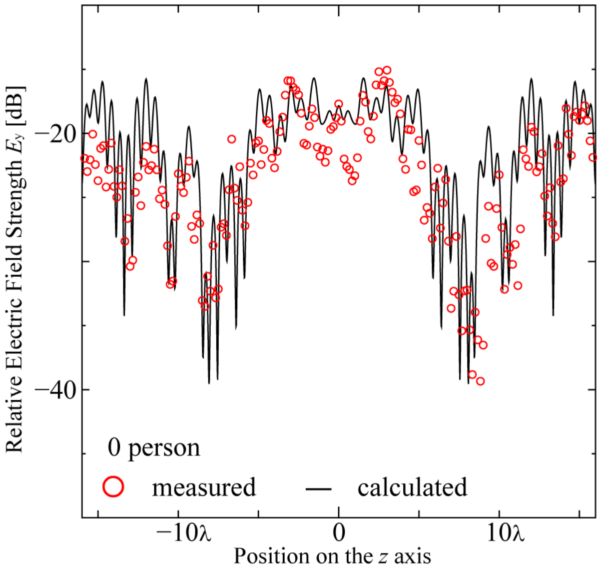

Fig. 2: Comparison between simulation and experimental measurements for the case of no humans inside the room.

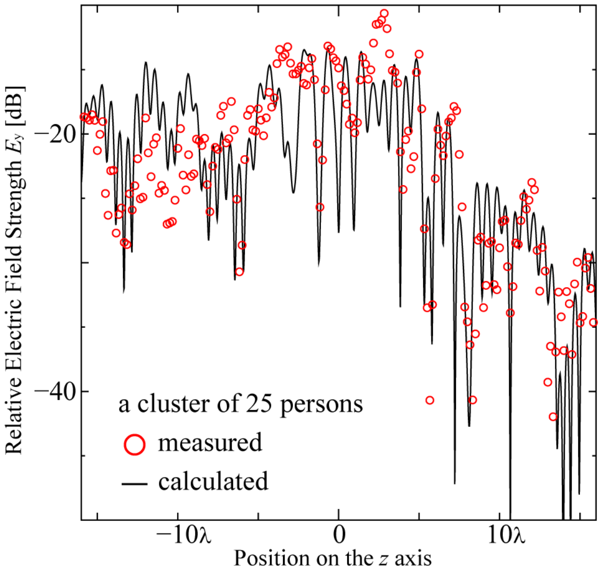

Fig. 3: Comparison between simulation and experimental measurements for the case of a cluster of 25 humans inside the room.

This fact can be highlighted by comparing the electric field strength for the case of no humans and the case of a cluster of 25 humans for both the simulated and the measured data sets. This is done in Fig. 4 and 5 respectively. The field distribution for the case of empty room can be used as a reference in order to understand when human presence takes place. For instance, in the right side of the z axis one can see that the red line (25 humans in a cluster centered in the middle of the right half side of the room) has lower strength compared with the black line (no humans case). This is evidence of electric field absorption due to the presence of humans. This is also shown in the left hand side of the room by noticing that red line and black line are following similar patterns. Clearly this indicates with good probability, that for the 25 humans case there are no humans in the left side of the room.

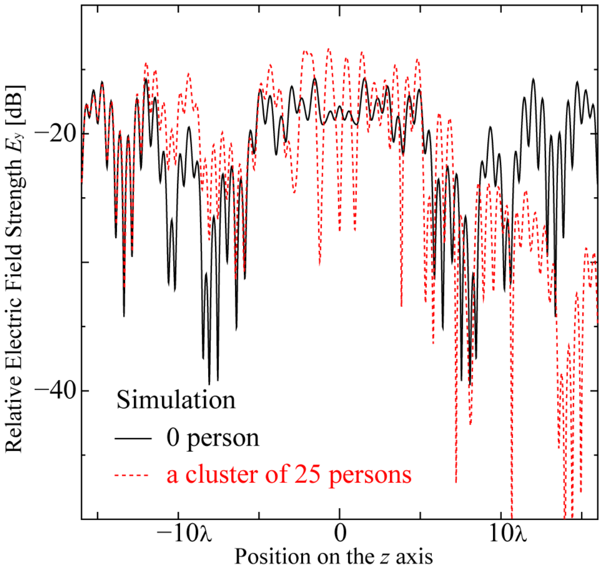

Fig. 4: Comparison between the simulated distributions of electric field strengths for the case of no humans and 25 humans in a cluster distribution.

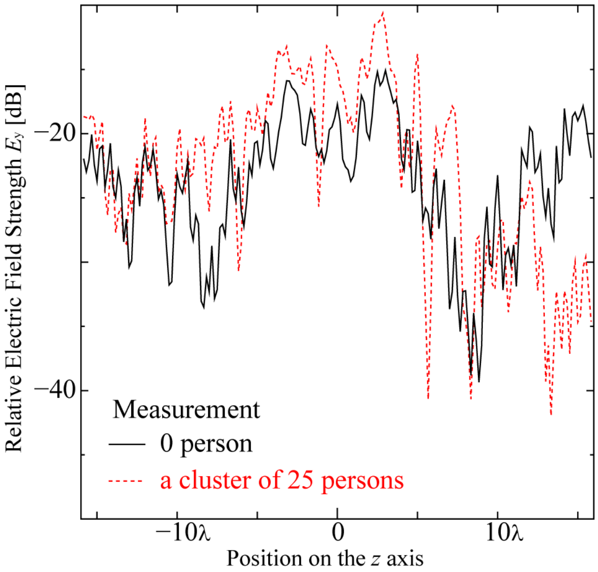

Fig. 5: Comparison between the measured distributions of electric field strengths for the case of no humans and 25 humans in a cluster distribution.

What previously described by reading the electric field strength measured along the z axis, can be better seen in the full 2D simulated data for the electric field in the room model depicted in Fig. 1. Fig 6 and Fig 7 show the two field distributions for the cases of no humans and 25 humans, respectively. The left side of the former case shows no disruption of the electric field distribution similarly to the case of no humans. This again indicates presence of humans only in the right side.

A further step in the estimation of presence of humans in the room can be shown by considering the difference between data collected for the case of no humans in the room and another case with humans in the room. Fig. 8 shows the electric field strength difference between data in Fig. 6 and 7 for example. This operation of subtraction enhances the position of individual humans. In fact where the electric field strength is similar for both cases (no humans or 25 humans) the difference is zero. This operation can be intended as a removal of the common background field strength between the two cases. Therefore it is possible to simulate a set of statistical patterns (or more realistic ones) in order to give field strength distributions which can be compared with actual measurements. Actual measurements which will best fit such simulated patterns will be strictly connected to the simulated case of known number and distribution of humans in the room. In order to put this concept in practice, more than one linear scan might be needed. For instance a further scan in the vertical direction will certainly improve the statistical determination of the number of people in the room if used in conjunction with the horizontal scan.

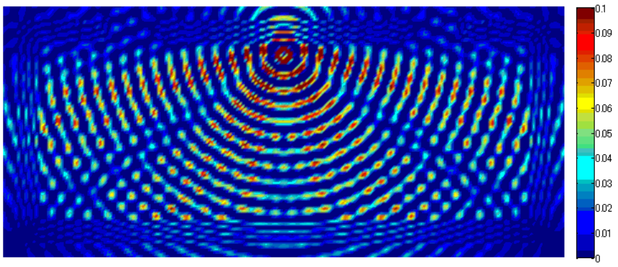

Fig. 6: Distribution of electric field strength obtained by the FVTD method when no humans are present in the room.

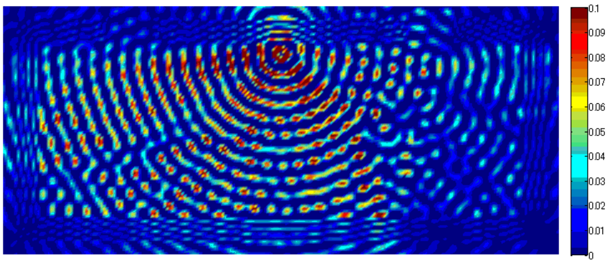

Fig. 7: Distribution of electric field strength obtained by the FVTD method when 25 humans are present in the right side of the room.

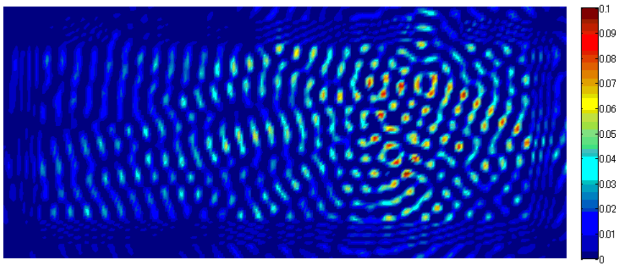

Fig. 8: Distribution of electric field strength difference between data in Fig. 6 and Fig. 7. High field strength indicates presence of humans.

4. Concluding Remarks

Electromagnetic waves propagating inside rooms where a cluster of people exists have been studied by using the FVTD computational method and experimental measurements. This work showed excellent agreement between simulation and experimental measurements of electric field strength along the horizontal axis of the room. The measurements obtained from the example brought in this paper of 25 humans located in a cluster on the right side of the room compared with the case of no humans in the room, allowed some important speculations on the effective possibility of determining the presence of humans inside the room. These results pose a fundamental milestone for the future developments of this work. In fact having established remarkable agreement between software and experimental measurements for this basic problem, more sophisticated human distributions can be studied via software simulations for understanding possible real world scenarios.

Next activities will include detailed statistical study of human distributions in order to precisely map how the number of people can be detected inside a room.

5. Acknowledgements

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6. References

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