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A Novel Channel Characterization Method Based on Ray Tracing for Human Fall Scenario

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Abstract

The integrated communication and sensing (ISAC) system is playing an increasingly important role in information interaction and environmental perception of smart home. In order to effectively evaluate the performance of ISAC devices, it is critical to understand the wireless channel characteristics. In this paper, the human fall motion channel at 4.9 GHz in the living room scenario is measured. A motion slice model is proposed to characterize the fall process. Based on the measured data, electromagnetic (EM) parameters of materials are calibrated. Using the calibrated ray tracing (RT) and human fall motion slice models to simulate multiple instantaneous states of the fall process. By comparing the power and phase between simulation and measurement, the feasibility of the modeling approach proposed is verified. The work of this paper can provide guidance for ISAC devices deployment of smart home, and the calibrated material EM parameters can be used for extensive simulation and modeling in living room scenarios.

1 Introduction

With the continuous development of technology, people have higher requirements for mobile communication. Relying on the 5G technology, the wireless communication system is further improved in terms of mobile communication quality, number of access devices, and reliable transmission of high-speed data. The smart home is recognized as one of the intelligent applications of 5G–A [1]. The integrated communication and sensing (ISAC) based on 5G that is promoted in 5G-A phase, it will contribute to the development of smart home. The effective application of ISAC in indoor improves the safety of people's home life and avoids many unnecessary accidents. By monitoring the home environment and sensing human movement in the room, the safety hazards in the home can be warned in advance.

To meet the goal of achieving health monitoring in smart home, the impact of human body on the wireless channel needs to be analyzed. The [2] analyzes the effect of human movements on the characteristics of a 60 GHz indoor wireless channel, recording a series of channel impulse responses up to 40 minutes. With the development of technology, ray tracing (RT) is widely used for wireless channel characterization around human body with its high efficiency. In [3], human body is modeled as cylinders and the effect of human on the channel characteristics in curved tunnels is simulated and analyzed. The [4] simulates the path loss parameters of human surface wireless channel at 60 GHz for both standing and crawling postures. In [5], the human head, torso and legs are modeled as prisms, the arms are modeled as cylinders, and the shadow effect of human body at 2.4 GHz and 60 GHz is characterized by RT simulation. However, most of the studies focuse on the additional loss caused by human shadows, the impact of human movements on the wireless channel is rarely been described.

Compared with the traditional 5G sub 6G band, 4.9 GHz has more advantages in avoiding cross time slot interference in the same frequency and facing uplink large bandwidth service capability [6]. In this paper, the indoor channel in the human fall state is investigated. Channel measurements are performed in the living room at 4.9 GHz with 1 GHz bandwidth. Based on the measured data, the delay and power of multi–path components (MPCs) are extracted to calibrate the RT simulator. The models of human fall motion slices and scenario are embedded into the calibrated RT simulator for simulation. Finally, by comparing the simulated and measured data, it is verified that the simulated power and phase can match well with the measured.

The rest of this paper is organized as follows. The section 2 describes the living room wireless channel measurement campaign. In section 3, the Motion slice mode is proposed, the electromagnetic (EM) parameters and RT simulator are calibrated, after which the decomposition process of falling is simulated using the calibrated RT and human fall motion slices. The conclusion is given in section 4.

2 Measurement campaign

2.1 Measurement system

The channel measurement system contains of a Keysight Agilent N5247A vector network analyzer (VNA), a tripod, a rotary table, a motion controller, a directional horn antenna, and an omnidirectional antenna. Figure 1 exhibits the channel measurement system diagram. The transmitter (Tx) is placed on the rotary table and connected to VNA port 2. The receiver (Rx) is fixed on top of the tripod and connected to VNA port 1. The laptop controls all systems through the dedicated software. Using laptop to command the main lobes of the Tx antenna rotate to a preset angle. The VNA performs the measurement and saves the measured data.

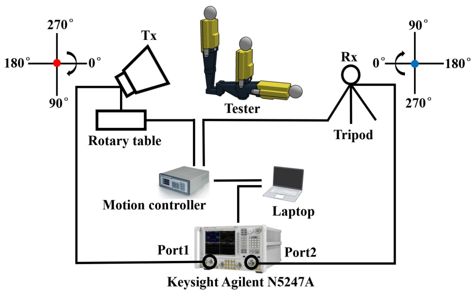
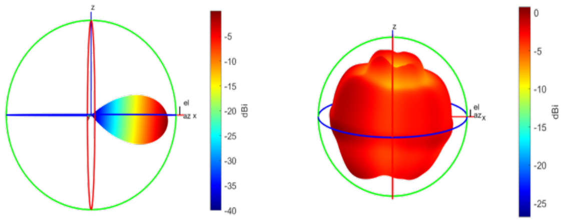


Figure 1. Schematic of the living room scenario.



(a) Tx (b) Rx

Figure 2. Antenna pattern

The measurement center frequency is 4.9 GHz, with the bandwidth of 1 GHz. The Tx antenna is a horn antenna with 19.81 dBi gain. The Tx antenna half–power beamwidth (HPBW) is 24°. In order to better capture the multipath of the human body kneeling and lying down when falling, the Tx antenna is set to elevation is 11.2°. Tx and Rx are deployed at 1.23 m and 0.8 m above floor, respectively. Figure 2 provide the antenna pattern of Tx and Rx at 4.9 GHz. The specific measurement parameters is in Table 1.

Table 1. Measurement setup

Parameter	Value
Center frequency [GHz]	4.9
Bandwidth [GHz]	1
Tx height [m]	1.23
Rx height [m]	0.8
Tx - Rx distance [m]	2.9
Tx Antenna gain [dBi]	19.81
Rx Antenna gain [dBi]	0

2.2 Measurement method

The channel measurement campaign is carried out in an indoor living room. The length, width and height of the living room are 7.1 m, 3.6 m and 2.6 m respectively. Falling is a dynamic and continuous process. Figure 3 shows the human fall process consists of three states: stand, kneel, and lay. The effects of the three different human postures on the radio channel are measured separately. The Tx position is kept constant and Rx is deployed at two different points. The measured data from one Rx is used to calibrate the EM parameters, and the other is used to verify the accuracy of the calibrated EM parameters.

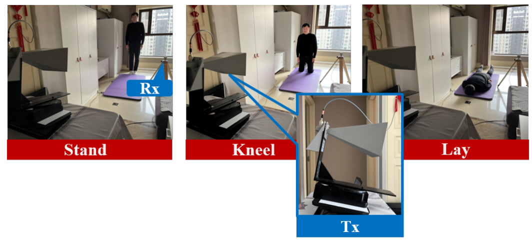


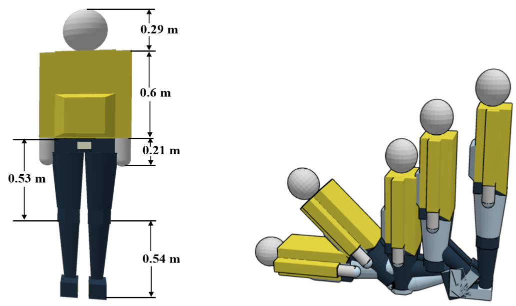
Figure 3. Measurement campaign in Living Room.

3 Motion slice model and simulation

In this section, we proposed a motion slice model to characterize multiple instantaneous states in the process of human fall. RT is used to extract the significant MPCs and match the MPCs with the corresponding objects. The material EM parameter of the object's surface is calibrated to ensure that the error between the measured data and the simulation result is minimized.

3.1 Motion slice model

Figure 4(a) shows the 3D model of the human body when standing. Figure 4(b) shows the fall process is split into multiple action slices. Taking Figure 4(b) as an example, multiple slices can be inserted between the different states of the fall process during the simulation.



(a) Human stand model (b) Motion slice model

Figure 4. Human body model

3.2 simulation

Taking the living room as the research scenario, as shown in Figure 5. The 3D digital modeling of common objects in the scenario, such as sofa, closets, walls, windows, etc. retaining their important details. The Tx and Rx are deploymented according to actual measurements scenario. According to RT simulation result, the main propagation mechanisms in this scenario are LOS and scattering. The model of scattering is directive scattering [7]. As shown in Table 2, ε_r, $\tan\delta$, S and α_R denote the real part of relative permittivity, loss angle tangent, scattering coefficient and equivalent roughness of the object surface, respectively.

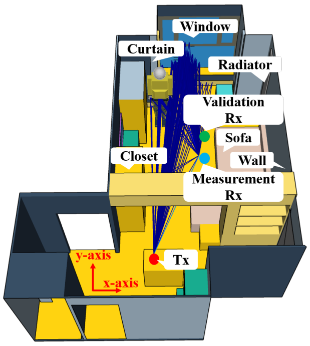


Figure 5. Living room scenario antenna deployment.

Table 2. EM parameters before and after calibration

Materials (Objects)	EM parameters							
	Before calibration				*After calibration*			
	ε_r	$\tan\delta$	S	α_R	ε_r	$\tan\delta$	S	α_R
Nylon (Abdomen)	5.1	0.100	0.025	1	3.8	0.001	0.370	1
Head (Head)	16.0	0.100	0.250	1	35.0	0.500	0.550	10
Jeans (Jeans)	5.1	0.100	0.025	1	21.0	0.001	0.360	10
Brick (Wall)	1.7	0.400	0.160	9	5.4	0.600	0.390	18
Fabric1 (Curtain)	3.4	5.000	0.300	7	5.0	0.800	0.500	9
Glass (Window)	3.2	0.007	0.210	8	7.5	0.600	0.550	13
Lattice (Window)	1.0	1e7	0.230	2	3.0	0.600	0.100	7
Pine (Closet)	1.0	0.500	0.500	6	1.1	0.200	0.110	1
Fabric2 (Sofa)	3.4	5.000	0.300	7	1.3	0.010	0.130	13

The motion slice and scenario 3D models, initial EM parameters, simulation link configuration are imported into the RT simulator. The simulation results are used to match the corresponding objects in the modeled scenario. When the tester stands with his back to the window facing Tx, the rays tracked is shown in Figure 5. Figure 6(a)(b)(c) show the CIRs for the three cases of stand, kneel and lay during the fall, respectively. It can be seen that the simulated MPCs matche well with the measured results in the delay domain. MPC1 is from the legs of the human body, MPC2 is from the windows, MPC3 is from the exposed hands and head of the human body, and MPC4 is from the curtains. Based on the simulation results obtained by this method, all the significant MPCs are not only indexed to the correct objects source, but also correctly matched to the measured data in the delay domain.

The initial parameter values before calibration are derived from long industry experience and team measurements. Based on the measured data and the 3D model, the surface materials of different objects are determined by geometric relationship. The simulation results are combined with the measured results to generate the cost function by adjusting the EM parameters until its convergence. The [8] describes the specific calibration steps. Table 2 shows the details of the EM parameters before and after calibration. Figure 6 displays the RT simulation results before and after calibration in three states: stand, kneel, and lay. In the stand state, MPC1 is mainly from the human legs. In the kneel and lay state, MPC3 is mainly from the human head and hands. Moreover, the MPC power from the exposed part of the body is greater than the part covered by clothes. The results simulated by the calibrated RT simulator can match well with the measured results.

To verify the accuracy of the calibrated simulator, under the same conditions of other configurations, the position of Rx is shifted in translation along the y-axis from the blue point to the green point, as shown in Figure 4. Figure 7 compares the simulation results with the measured results in the three states of stand, kneel and lay during the fall. With the same EM parameters, the delay and power of MPCs from closet (MPC1), human (MPC2), curtain (MPC3) and window (MPC4) obtained by RT simulation are match well with the measured results. Table 3 summarizes the errors of all matched MPCs. As can be seen from the table all errors are within 3 dB. Compared to other objects, the errors are larger for windows and human head. This is due to the presence of multiple layers of propagation in windows, and the model of human head is complicated. The results show that the 3D model of the scenario and human motion slice, the simulation configuration of RT and the calibrated EM parameters are all reasonable. The reliable and robust simulation results can be produced in various situations.

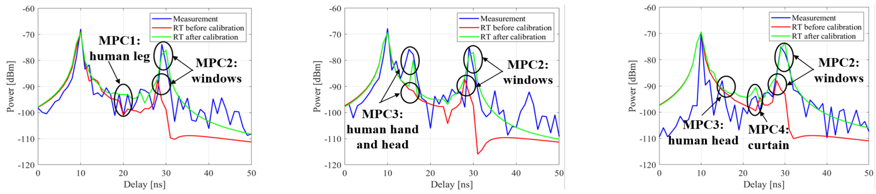
Table 3. MPC power calibration results

Case	MPC source	Measured result [dBm]	Calibrated result [dBm]	Error [dB]
stand	human leg	-92.94	-93.12	0.18
	windows	-74.80	-77.60	2.80
kneel	human hand and head	-93.22	-94.80	1.58
	windows	-74.88	-77.63	2.75
lay	human head	-87.52	-90.26	2.74
	curtain	-95.34	-93.05	2.29
	Windows	-75.12	-75.62	0.50

4 Validation

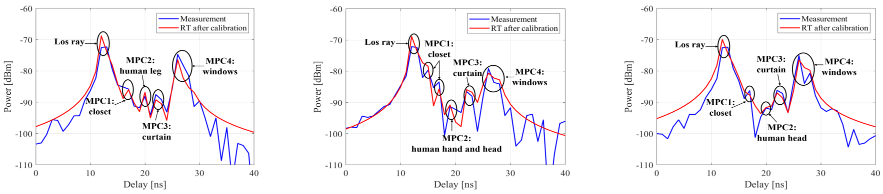
In this part, the continuous process of the fall (from stand to lay) is studied using the calibrated RT simulator. During stand to kneel, the angle of the lower legs are adjusted every 18° from 0° in standing to 90° in kneel. During the process of kneel to lay, the position of the lower legs remain the same, and the torso above the knee is adjusted as above. The motion slices of the fall are obtained as shown in Figure 4(b). VNA can collect the power and phase changes of the received signal during the fall of the tester.

Figure 8 shows the continuous wave (CW) results between measurement and simulation. As shown in Figure 8(a), the power is higher during kneel (about -86.09 dBm) than during stand (about -80.49 dBm) and lay (about -85.48 dBm). The phenomenon indicates that the exposed part of the human body is able to bring more scattering rays with greater power compared to the part covered by clothes. Figure 8(b) shows that using the RT simulator and adjusting the interval time of the fall slices, it is possible to reproduce a continuous change in phase similar to the measurements. Therefore, the dynamic process of falling can be detected by continuous changes of power and phase.



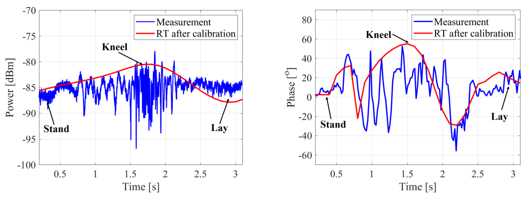
(a) Stand case (b) Kneel case (c) Lay case

Figure 6. Calibration result



(a) Stand case (b) Kneel case (c) Lay case

Figure 7. Simulation and measured result



(a) Measurement (b) Simulation

Figure 8. CW result

5 Conclusion

In this paper, we measure the wireless channels of human fall process in the living room at 4.9 GHz. To characterize the fall process, We proposed a motion slice model. Based on the model, we use RT to characterize the wireless channel changes in multiple instantaneous states during the fall process. The measured data is combined with RT simulation data to identify typical objects that can bring significant MPCs, including human, window, curtain and closet. The EM parameters of the object surface materials are calibrated to ensure that power errors of simulated MPCs are within 3 dB. By using the calibrated RT simulator and the modeling approach of falling slices, the reliability of this simulation method has been verified under different Rx deployment positions. The outcomes indicate that compared with the part covered by clothes, the exposed part of the body can bring more rays with greater power. Therefore, the power when kneel is greater than that when stand and lay. The maximum phase difference during falling can reach 90°. By using the methods of simulation and fall slices modeling proposed in this paper, the wireless channel changes during the fall process can be well characterized. The RT-based deterministic modeling approach proposed in this paper will be useful for performance evaluation of ISAC system and smart home health monitoring applications.

Acknowledgements

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