

## Improvement of Radio Propagation Estimation Accuracy by Completing Plane-Based 3D Models Obtained with Depth Sensors

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### Abstract

In order to improve the estimation accuracy of radio propagation simulation using a 3D model reconstructed by depth sensors, recovering missing regions of the 3D model is important. In this paper, we report an evaluation result of indoor radio estimation accuracy by using such a completed 3D model. We first describe the evaluation scene and the measurement method of radio powers we used for experiments. We then give an overview of the method for reconstructing and completing a 3D model of the evaluation scene. Finally, we compare simulation results obtained with the original model and the completed model against the real measurements. The errors obtained with the original and completed model were 2.40 dB and 2.16 dB respectively, demonstrating the effectiveness of the 3D model completion for the indoor radio estimation.

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# Improvement of Radio Propagation Estimation Accuracy by Completing Plane-Based 3D Models Obtained with Depth Sensors

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**Abstract**—In order to improve the estimation accuracy of radio propagation simulation using a 3D model reconstructed by depth sensors, recovering missing regions of the 3D model is important. In this paper, we report an evaluation result of indoor radio estimation accuracy by using such a completed 3D model. We first describe the evaluation scene and the measurement method of radio powers we used for experiments. We then give an overview of the method for reconstructing and completing a 3D model of the evaluation scene. Finally, we compare simulation results obtained with the original model and the completed model against the real measurements. The errors obtained with the original and completed model were 2.40 dB and 2.16 dB respectively, demonstrating the effectiveness of the 3D model completion for the indoor radio estimation.

**Keywords**—indoor radio propagation, geometrical optics, ray tracing, depth sensor, 3D model, plane-based model, completion

## I. INTRODUCTION

Recently, due to the emergence of the Internet of things, radio propagation estimation [1] has become important in order to place wireless devices efficiently. Typically the most time-consuming step for radio simulation is the preparation of a 3D model of the target area, and thus utilizing a 3D model reconstructed by depth sensors [2, 3] is effective to decrease the total radio design time and cost. However, measuring the structures without missing data is difficult, because the sensor can measure the structures only in the line of sight from the sensor position, and the sensor's measurement range is also limited. The incompleteness of the 3D model affects the radio estimation accuracy. Therefore, recovering missing regions of the 3D model is important. In this paper, we report an evaluation result of radio estimation accuracy obtained with original and completed 3D model, and clarify the effect of 3D model completion.

Section II describes the evaluation scene and measurement method of radio powers. Section III shows the methods for reconstructing a plane-based 3D model using depth sensors and for completing the 3D model. Section IV presents the evaluation result of radio calculation accuracy obtained with the original and completed models. Finally, Section V concludes this paper.

## II. MEASUREMENT OF RADIO POWERS

We used as the evaluation scene an office floor whose dimension is  $40\text{m} \times 15\text{m} \times 2.7\text{m}$  as shown in Figure 1. The scene had some desks with 1.5m height partitions aligned to the  $x$ -direction. A single omnidirectional transmitter was placed at 2.4m height. Receiving power was measured by moving omnidirectional antennas along the paths denoted by the red solid lines. The height of the receivers was set to 2.3m. The motion was almost constant walking speed with 100ms observation intervals, therefore the distance of each measurement was about 5cm. In order to remove fast fading, the received powers were smoothed with a window of  $\pm 20$  points (about  $\pm 1\text{m}$ ) for the evaluation described in Section IV.

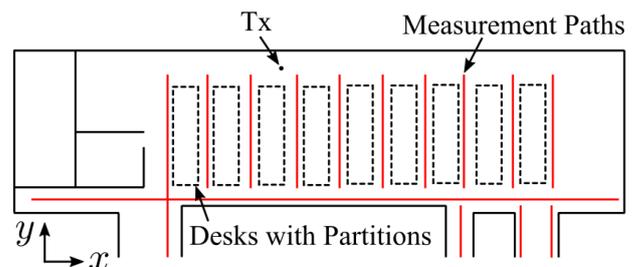


Fig. 1. Floor plan of the evaluation scene and measurement paths on which the radio receiving power was measured using omnidirectional antenna.

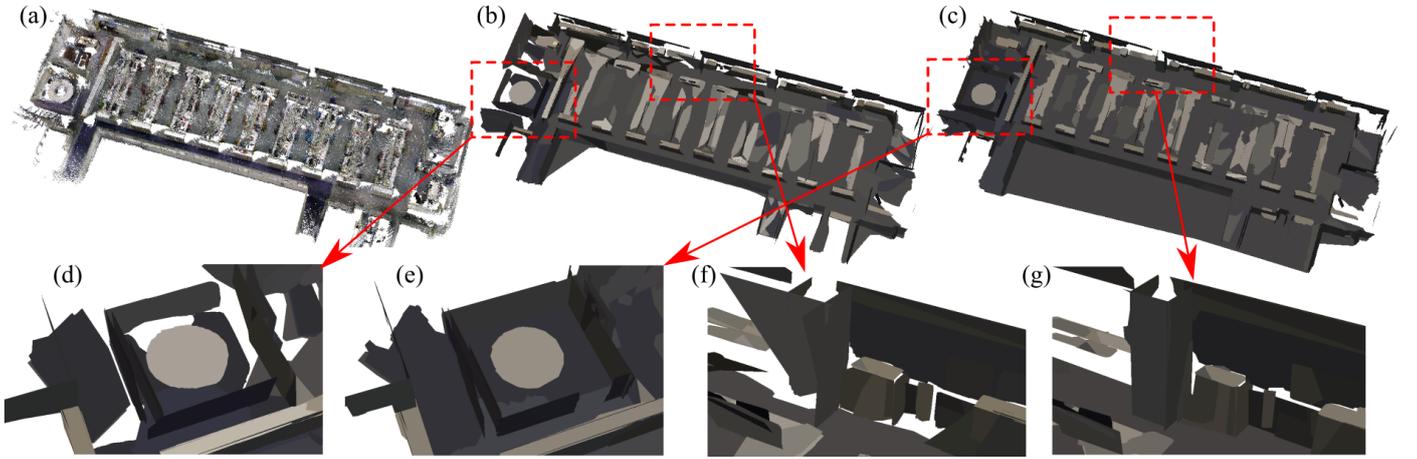


Fig. 2. Reconstructed 3D models of the evaluation scene. (a) Point cloud model. (b) Original plane-based model. (c) Completed plane-based model. Close-up views of (d, f) the original model and (e, g) the completed model.

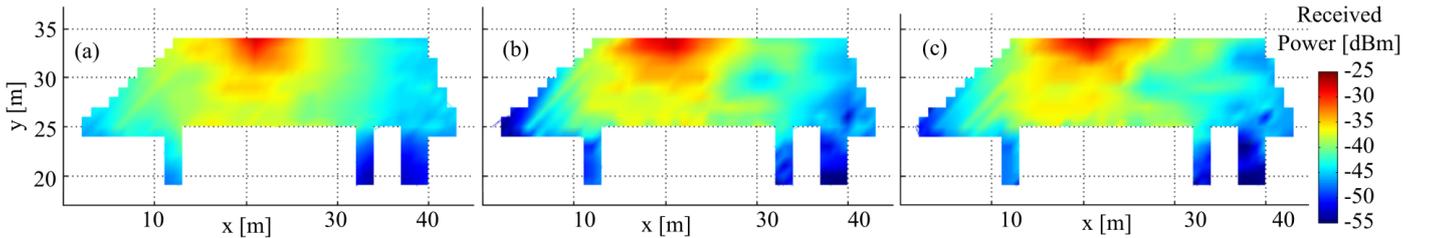


Fig. 3. Received powers in evaluation scene. (a) Measurement. (b) Simulated using original plane-based model. (c) Simulated using completed plane-based model.

### III. 3D MODEL RECONSTRUCTION AND COMPLETION

We used six portable RGB-D sensors in the point-plane SLAM (simultaneous localization and mapping) system [3] to reconstruct a 3D model of the evaluation scene as shown in Figure 2. Figure 2 (a) is a colored point cloud obtained by registering the RGB-D frames according to the sensor poses computed by the SLAM system. The SLAM system also generates a plane-based model as shown in Figure 2 (b), which is useful for radio simulation, because boundaries and normals of the structures are explicit. In this model, however, there are several missing regions. We filled missing regions on individual planes by interpolation and missing regions existing around the intersections of planes by extrapolation toward the intersection lines to obtain a completed plane-based model shown in Figure 2 (c). It can be seen that many of the missing regions were filled and the boundaries became more accurate in the completed plane-based model.

### IV. EVALUATION OF RADIO SIMULATION ACCURACY

In this section, we report the comparison result of the received powers simulated using the original and completed plane-based models with the real measurements. Figure 3 (a) shows the color map of the measured received powers in the evaluation scene. In order to evaluate the global estimation error in the scene, the received powers on 434 points on a uniform grid (0.5m interval) were computed by an interpolation from the measurements along the paths. For the interpolation, the linear interpolation after Delaunay triangulation was used. Figures 3 (b) and (c) show simulated received powers using the original and completed 3D model respectively. The simulated received powers were calculated

using a geometrical-optics-based method with ray tracing along the same paths, and using the same interpolation method as the real measurements. The simulation accuracy was evaluated by RMS error  $\sigma$  [dB] from all interpolated points as  $\sigma = \sqrt{\sum_{i=1}^N (P_{sim,i} - P_{meas,i})^2 / N}$ , where  $P_{sim,i}$  and  $P_{meas,i}$  are the  $i$ -th simulated and measured received power respectively, and  $N$  is the number of interpolated received powers. The  $\sigma$  obtained using the original model was 2.40 dB, while that obtained using the completed model was 2.16 dB. Although both simulations had good estimation accuracy, the completed model provided slightly better accuracy than the original model.

### V. CONCLUSIONS

This paper evaluated the estimation accuracy of the radio simulation using the plane-based model obtained with depth sensors with completion of missing regions. The simulation of the received powers in the office scene with completion provided better result (0.24 dB), demonstrating the effectiveness of 3D model completion for radio simulation.

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