Simplification Method of 3D Point Cloud Data for Ray Trace Simulation in Indoor Environment

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Abstract: With the advent of IoT (Internet of Things) services in recent years, various industries are now working towards operating wireless networks and this in turn gives rise to the need for radio propagation simulations. However, in order to obtain reliable simulation results, an accurate model of the environment is often needed. This paper proposes a method for generating a plane model automatically, for use in ray tracing simulations from 3D point cloud data in order to ease the burden of creating models manually. Ray tracing simulation results using the generated model are compared with measurements and the comparison shows that the trend of normalized received power is similar.

Keywords: Ray trace, Point cloud data, Indoor environment

Classification: Antennas and propagation

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1 Introduction
With the advent of IoT (Internet of Things) services in recent years, various industries are now working towards building and operating wireless networks for their own application. Traditionally, mobile operators are the ones who are largely involved in designing wireless networks, and they have widely used radiowave propagation simulation for this task.

In order to perform an accurate radiowave propagation simulation, a detailed environmental model is often required, especially so when simulating in the millimeter wave bands. As such, it is difficult for users to design their own wireless network and this poses a challenge for the dissemination of IoT services. This research aims to support these users by allowing them to design a wireless network with less effort.

Recently, point cloud data, which is a set of data points in 3D space acquired by scanning the environment, has become increasingly accessible. For radiowave propagation simulations like ray tracing, point cloud data cannot be used as is and needs to be simplified into planes. In this paper, in order to reduce the burden of constructing a model for ray tracing simulation, a method that automatically generates a simplified planar model using 3D point cloud data that can be easily acquired is presented. To check if the generated simplified model is appropriate for radiowave propagation, ray tracing simulation results using the generated simplified model are compared with channel sounding measurements.

This paper is organized in the following manner. Section 2 of this paper explains the method that was used to create a plane model that is suitable for use with ray tracing simulations. The details of the point cloud data acquisition and radiowave propagation measurement and simulation are presented in section 3 and section 4 evaluates the results. Finally, section 5 presents the conclusion.

2 Plane model creation method using point cloud data
For many simulation programs, 3D computer aided design (CAD) models are often more appropriate and convenient to use as compared to point cloud data. Despite this, 3D CAD models may not be readily available, especially for places that are built long ago. This gives rise to the need to create a 3D CAD model from scratch which could take a lot of time. In order to create 3D models from point cloud data, some researches focus on extracting planes to reconstruct the environment. However, they do not guarantee that the created model will be free of gaps which is important when doing radiowave propagation simulations like ray tracing. It also does not address the case when there are walls that extrude from the main wall. This paper proposes a method to fix these issues based on our previous work which used a laser scanner to acquire the point cloud data [1]. Furthermore, indoor environments are mostly composed of vertical and horizontal planes. Taking this into consideration, this paper proposes to automate and simplify the
generation of 3D indoor models from point cloud data suitable for ray tracing method. To do this, the following 8 processes were deployed using the Point Cloud Library (PCL) [2].

(1) Down sampling. One point cloud file contains millions of points. To speed up and decrease memory usage of the subsequent process, the Voxelized Grid approach is used as the down sampling filter.

(2) Segmentation. This process groups point cloud data into multiple clusters. The basic idea is to examine the curvature and normal values of surrounding points to determine if the points should be regarded as the same region.

(3) Plane detection. The Random Sample Consensus (RANSAC) [3] method was used to extract a finite plane model for each cluster. The plane model is defined by the following function:

\[ ax + by + cz + d = 0 \]  

The boundaries of each plane are then determined by the outermost point of its corresponding cluster.

(4) Classification of planes. The planes that are detected in the previous step are categorized into horizontal, vertical or ceiling/floor. Ceiling/floor planes are special horizontal planes and are found by finding the 2 largest horizontal planes. The height of the room can then be estimated by taking the difference in height between these 2 planes. In the subsequent processing, the horizontal and ceiling/floor planes will not be used.

(5) Plane regeneration. All the main walls in a room are expected to start on the floor and end at the ceiling. In this step, a correction will be applied to alter the height of all the main walls. Main walls are defined as walls whose height is more than 95% of the room height. This step removes gaps between the main walls and the floor and ceiling.

(6) Wall combinations. In this step, the edges of wall planes are connected to remove gaps that appear due to inaccuracies in the point cloud data. For one edge of the plane, the nearest edge of the other planes is determined and another plane is then generated to connect the 2 planes. A distance threshold is set between 2 edges to prevent incorrect connections.

(7) Extension of planes. Vertical planes whose height are less than 95% of the room height are assumed to be planes that extrude from the main walls of the room. The algorithm in Fig. 1 is used to find these planes and extend it and connect it to the main wall planes. First, the projection of the small vertical plane on the wall plane is determined. Thereafter, the 4 planes that are required

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**Fig. 1.** Input and algorithm to find target wall for extension
to connect the edges of the small vertical plane to the main wall plane is subsequently determined. Lastly, the projection area of the small vertical plane is removed from the main wall plane. In this manner, main wall planes with holes can be correctly generated.

(8) Roof and ground filling. Using the vertices of the main wall planes, ceiling and floor planes are generated. It is assumed that both ceiling and floor planes are completely flat, i.e., existing beams or hanging lights are not reconstructed.

3 Measurement and simulation

The point cloud data that is used in this paper was acquired from a conference room as shown in Fig. 2(a) at Tokyo Institute of Technology, Ookayama Campus using a Structure Sensor (instead of a laser scanner in [1]) which can be easily mounted on an iPad and is relatively inexpensive. During data acquisition, there was no furniture. Data was taken from multiple positions, and the point cloud registration algorithm was used to merge the different data pieces together. Resolution of point cloud data ranges from 1 cm to 11 cm with an average of 8 cm. The size of the room is approximately 8.70 m x 17.60 m x 3.00 m.

![Figure 2](image)

(a) Measurement area  
(b) Propagation route  
(c) Measurement and simulation parameters

| Parameters                  | Measurement                      | Simulation                           |
|-----------------------------|----------------------------------|--------------------------------------|
| Center frequency            | 11 GHz                           | 11 GHz                               |
| Bandwidth                   | 400 MHz                          | -                                    |
| Transmit power              | 10 mW                            | 10 mW                                |
| Number of tones             | 2048                             | -                                    |
| Measurement resolution      | 2.5 ns                           | -                                    |
| BS/MS Antenna type          | 12-element circular antenna array (12 v-pol and 12 h-pol) Beamwidth for each element: Horizontal: 100°; Vertical: 35° | Omnidirectional antenna Vertical polarization |
| BS/MS Antenna gain          | 6 dBi                            | 0 dBi                                |
| BS/MS Antenna height        | 1.7 m                            | 1.7 m                                |
| Model material              | Metal (relative permittivity = 1, conductivity = 1e7[S/m]) | -                                    |
| Max number of Reflection    | -                                | 5                                    |
| Max number of Diffraction   | 1                                |                                      |
| Max number of Ref + Diff    | 5                                | 5                                    |

Fig. 2. (a) Photograph of measurement area. (b) Propagation route.  
(c) Measurement and simulation parameters.

In order to verify the usability of the generated simplified model in terms of radiowave propagation, a ray tracing simulation using RapLab was performed and
the results were compared to channel sounding measurements [4] in the same location. RapLab is a commercial ray tracing simulator based on the method of images [5]. To search for single reflection paths, an image of the receiver (Rx) with respect to a surface is created and a line is drawn from the transmitter (Tx) to the image of Rx to determine the intersection point on the surface. The reflection path will then be composed of Tx, the intersection point and Rx. The image method can be extended to determine multiple interactions.

The specifications of the channel sounder are shown in Fig. 2(c). The Tx/Rx antenna arrays are 12-element circular arrays with dual-polarized patch antennas. During measurement, there was no furniture and the mobile station (MS) was moved to the left towards the base station (BS) at a speed of approximately 0.25 m/s as shown in Fig. 2(b). The total number of MS location is 140. For the ray trace simulation, a maximum of 5 reflections and maximum of 1 diffraction was used. The front and back part of the room are walls mounted with metallic whiteboard. The floor is concrete while the ceiling is lined with fluorescent lights inside metallic casings. Since most materials are metal, the simulation model material used is metal.

4 Comparison of results with actual measurements

Fig. 3(a) shows the original point cloud data and Fig. 3(b) shows the generated simplified model, respectively. The size of the generated model is 8.40 m x 17.52 m x 2.90 m as compared to the actual size which is 8.70 m x 17.60 m x 3.00 m. There are 2 extended vertical planes shown on the right wall of Fig. 3(b). The simplified results give 3.50 m x 2.10 m x 1.02 m, and 5.23 m x 2.10 m x 1.20 m, as compared to the actual size of 6.14 m x 2.21 m x 0.96 m, and 5.84 m x 2.21 m x 1.06 m respectively. The whole program can be finished within a few seconds.

![Fig. 3.](image)

(a) Point cloud data  
(b) Generated simplified model  
(c) Comparison of delay profile  
(d) Comparison of CDF

Fig. 3. (a) Point cloud data. (b) Generated simplified model with ceiling and floor hidden. (c) Delay profile comparison at 0 m. (d) CDF comparison for all measurement points.
In terms of radiowave propagation, Fig. 3(c) compares the measured and simulated delay profiles when the MS is at 0 m (farthest location from BS). Since the measurement resolution is 2.5 ns, the simulated delay profiles are also combined for every 2.5 ns. For comparison, both measured and simulation results are normalized using their respective maximum power. It can be seen from the graph that the peak positions are in good agreement between the measurement and the simulation, and the specular multipath components (SMC) are well reproduced by the simulation. Despite this, it can also be seen that the normalized power is generally lower in the simulation as compared to the measurement. This is largely due to the fact that dense multipath components (DMC) due to scattering effects such as diffuse scattering are not considered in the simulation. However, since material properties such as wall roughness have a larger effect on DMC than the shape of the room, it can be concluded that the generated simplified model from point cloud data, which can reproduce the SMC results relatively well, is a good representation of the actual room for radio propagation simulations.

Fig. 3(d) shows a comparison of cumulative distribution function (CDF) obtained from the received power at all 140 measurement points for the measurement and simulation. Received power for each position $s$, $P_r(s)$, is divided by the received power of the nearest MS to BS, $P_r(s=s_1)$, to obtain $P'_r(s)$ as shown in Eq.(2). Note that $P_r(s)$ is the sum of the delay profile at position $s$.

$$P'_r(s) = \frac{P_r(s)}{P_r(s=s_1)} \quad (2)$$

Fig. 3(d) shows a comparison of $P'_r(s)$. The graph shows the range of the measurement received power and range of the simulated received power differs by less than 2 dB.

5 Conclusion
In this paper, a method was proposed to automatically generate a simplified planar model from 3D point cloud data gathered using relatively inexpensive and easy to use Structure Sensor, for use in ray tracing simulation. This could reduce the burden and time to construct 3D models for simulation. The simplified model could replicate the ceilings, floors, main walls and extend planes without gaps which is important for radiowave propagation simulations.

Ray tracing simulation results using the generated simplified model compared with measurements show that the specular multipath components are well reproduced by the simulation although the normalized power is generally lower in the simulation due to the absence of dense multipath components. The CDF for all measurement points show the same trend for both measurement and simulation, and the difference is less than 2 dB.

The proposed method assumes that the ceiling and floor of room are parallel and flat. Objects in the room are not modeled and only rectangular planes are constructed. Material properties are also not defined automatically. Future works will address the above constraints to develop a more generalized method.

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