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A Novel 3D Ray-tracing Model for Precise Mobile Localization Application

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Abstract—Recent year has seen the need for precise localization for both commercial and government applications. The underlying building block for accessing the performance of the localization algorithm is either the channel measurement data or ray-tracing algorithms that are highly correlated to the empirical channel measurement data. However, the accuracy of ray tracing algorithm is highly related to the simulation of all possible propagation paths traversing through various structures in the realistic environment. Traditionally, most of the rays tracing algorithms have been well researched for planar structures. This paper presents a novel three-dimensional ray-tracing model for building structures with non-planar or curved surfaces. Methodology to overcome the problem in modeling scatterers with non-planar surfaces has been proposed. It takes into all possible propagation paths from any combinations of reflections, diffractions and transmissions from/through planar and non-planar/curved surfaces. Comparisons between proposed model and the measured power delay profile in an environment containing building structure with curved surfaces has shown good agreement and articulate the impact of including scattering phenomenon from curved surfaces on the power delay profile.

1. INTRODUCTION

Due to the advent of antenna array [1, 2], localization has been a prevalent research topic [3, 4]. Usually, experimental campaign is conducted to assess the design performance of the localization scheme. However, in recent years, ray tracing [5, 6] is used as the simulation tool to mimic the actual environment instead of conducting extensive measurement campaign. As such, to have a holistic comparison of the localization schemes, the ray tracing methodology must able to model the environment and trace out all propagation paths as accurately as possible.

Most of the ray-tracing models make use of multiple-image concept to facilitate the tracking and calculating of the rays which finally arrive at the receiver, provided the location of all the images involved can be determined. Although the image-based ray-tracing model can compute extremely complex ray paths and have shown reasonable prediction accuracy, it is limited to modeling scattering from polygonal scatterers and not curved surfaces. Thus, curved cylindrical scatterers are often approximated using polygonal scatterers [7]. In order to achieve a more realistic model, it is necessary to increase the number of sides of the polygonal scatterers used to approximate the curved cylindrical scatterers. However, the number of sides of the polygonal scatterers have to be limited in order that the computation time is not excessively long and solution based on the UTD are valid. This is because in ray tracing models based on the multiple image theory, an increase in the number of planar surfaces in the environment will result in an exponential rise in the number of reflection images generated, which in turn will result in a large number of ray traced.

The purpose of this paper is to derive a comprehensive three-dimensional ray-tracing model for microcellular communications, which can include all possible propagation paths from any combination of arbitrary number of reflections, transmissions and diffractions from multiple edges and convex surfaces. Furthermore, by incorporating the concept of cones of rays as in [5], the computation time can be shortened by examining whether the receiver is within reach of the cone of rays of a particular image, thus greatly reducing the number of images or rays to be tested.

2. THEORY AND FORMULATION

Figure 1(a) shows the plan view of a point source transmitter $T_x$ in a communication microcell in the campus of the Nanyang Technological University in Singapore. All buildings’ surfaces, parapet walls, and floor are constructed of concrete. The transmit antenna $T_x$ is positioned $h_t$ above the ground. A vertically polarized receiving antenna $R_x$ is placed $h_r$ above the ground, and its position is moved around the building corners. In modeling the environment shown in Figure 1(a), the ray-tracing models based on multiple image concept in the literature can only model the semi-cylindrical buildings using polygonal approximation.

Consider now a ray path $T_X-R_J-R_K-R_L-R_M-R_X$, with reflections from two planar and two convex surfaces. Using the multiple image concept, we can generate the reflection image $E^I_J$ due...
to $T_x$ associated with planar surface $J$. However, we cannot determine the next reflection image associated with convex surface $K$ due to equivalent source $E^{J}_{1}$. If the image associated with a curve cylindrical scatterer cannot be determined, the ray-tracing algorithm will fail when encountering such object because subsequent images can be generated only when the current image location is known.

As such, the concept of our proposed technique is to cascade the positional information of the curved cylindrical scatterers into the images until backward ray tracing is performed. In our new improved ray-tracing algorithm, reflection images for planar surfaces are computed as in [6, 7]. However, when encountering curved cylindrical scatterer, no reflection image associated with the cylindrical scatterer will be computed. Instead, the source illuminating the cylindrical scatterer and the positional information of the scatterer will form the “source” for subsequent scattering events. In general, whenever a curved surface is encountered during the ray tracing procedure, the positional information of the curved surface is combined with the illuminating source to form the new image. By adding the information of the curved surface in the image to generate subsequent images, this technique resolves the deadlock in conventional ray tracing algorithm when modeling curve cylindrical scatterers.

To determine the ray path $T_{X}-R_{J}-R_{K}-R_{L}-R_{M}-R_{X}$ using our proposed technique, we first compute the image $E^{J}_{1}$ associated with plane $J$ due to source $T_x$. Next, instead of computing the image associated with cylindrical scatterer $K$ due to the equivalent source $E^{J}_{1}$ which is not possible because the point of reflection on plane $L$, $R_{L}$, has yet to be determined, we combine the curved cylindrical scatterer $K$ and the equivalent source $E^{J}_{1}$ to form the reflection image associated with scatterer $K$. The reflection image associated with plane $L$ is then obtained by reflecting the image of scatterer $K$ about plane $L$. This image associated with plane $L$ will contain two set of information — $E^{KL}_{2}$ and $E^{KL}_{3}$ due to scatterer $K$ and source $E^{J}_{1}$ respectively. For the next reflection from cylindrical scatterer $M$ — $E^{JL}_{3}$, $E^{KL}_{2}$ and cylindrical scatterer $M$ are combined to form the reflection image associated with scatterer $M$.

To determine the path of the ray $T_{X}-R_{J}-R_{K}-R_{L}-R_{M}-R_{X}$, we proceed to perform backward ray tracing [7]. From the position of receiver $R_x$ and last generated reflection image due to cylindrical scatterer $M$, we first compute the points of reflection $R_{M}$ and $R_{K}'$ on the cylindrical scatterer $M$ and $E^{KL}_{2}$ respectively. With $R_{M}$ and $R_{K}'$ computed, the point of reflection on plane $L$, $R_{L}$, is given by intersection of plane $L$ and ray path $R_{K}'-R_{M}$. The point of reflection on cylindrical scatterer $K$, $R_{K}$, is given by reflection of $R_{K}'$ about plane $L$. Finally, $R_{J}$ is computed from the intersection of plane $J$ with ray path $E^{J}_{1}R_{K}$. By combining the information of cylindrical scatterers into the images, our proposed technique resolves the difficulty of tracing cylindrical scatterers in conventional ray tracing algorithm.

When implementing the improved technique, an approximation for the points of reflection on the cylindrical scatterers is required. This is because our proposed technique causes all cylindrical scatterers encountered along the ray path to be grouped together when backward ray tracing is performed. As analytical solution to points of reflection on cylindrical surfaces does not exist and numerical solution causes excessive computation time, we use an approximate method, which can be computed efficiently. From Figure 1(b), the approximated point of reflection on cylindrical scatterer $K$, $R_{K}$, is computed by taking half the angle subtended by $T_{X}O_{K}$ and $O_{K}O_{M}$. Similarly, the point of reflection on cylindrical scatterer $M$, $R_{M}$, makes equal angle with $R_{X}O_{M}$ and $O_{M}O_{K}$. As can be seen in Figure 1(b), this approximation produces results, which is very close to the actual points of reflection on the cylindrical scatterers.

3. RESULT AND DISCUSSION

Figure 2 shows the predicted and measured power delay profile at point 8 in Figure 1(a). The result shows that our model is able to predict, with reasonable accuracy, the various multipath signal components, i.e., many of the multipath components are predicted by our model and experimentally verified as having the correct delays. The dominant signal paths within the first 70 ns is mainly due to diffractions from the edges of the buildings adjacent to $T_x$. The results also show that signal components arriving after about 100 ns reach the receiver via transmission paths through the semi-cylindrical building. From Figure 2, it is significant to note that the predicted field strength of ray path $T_{X}-R_{J}-R_{K}-R_{L}-R_{M}$-$R_{X}$ as illustrated in Figure 1(a), which has a path delay of 180 ns ($\sim 60$ m), is close to the measured signal level around this range of delay time. Thus, the ability to predict such multipath signals improves the prediction accuracy of the propagation model.
Figure 1: (a) Plan view of measurement site and typical ray path with reflection from cylindrical scatterer. (b) Approximation of reflection points on cylindrical scatterers.

Figure 2: Comparison between predicted and measured delay profile at Point 8 of Figure 1(a).

We have also computed the path loss and rms delay spread $\tau_{rms}$ from the delay profiles for the measurement route in Figure 1(a). All $\tau_{rms}$ were computed for a dynamic range of 40 dB and delay time of 200 ns. The standard deviation between the measured and predicted path loss obtained using our improved model is 2.8 dB whereas for the model in [6], the standard deviation is 2.9 dB. The good agreement between the measured and predicted results shows the validity of ray-tracing model in predicting path loss coverage, and that diffraction/reflection from cylindrical scatterers may not have much effect on path loss prediction. However, compared to path loss, $\tau_{rms}$ is a much more sensitive parameter as it is dependent on both the signal strength and distribution in the delay profile.

4. CONCLUSION

A general three-dimensional ray-tracing model based on the UTD and multiple image theory is presented. This model developed overcomes the major limitation of modeling only polygonal scatterer in image based ray-tracing model. The model also includes convex surface diffraction and diffractions from multiple straight edges. Good agreement between predicted and measured results indicates that the accuracy of the ray-tracing model is a useful prediction tool for microcellular communications.
REFERENCES


