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Concept of Image Based Non-line-of-sight (NLOS) Localization in Multipath Environments

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Abstract— Current bidirectional localization schemes are able to locate a mobile device using Line-of-Sight (LOS) or Non-Line-of-Sight (NLOS) Time-of-Arrival (TOA) and Angle-of-Arrival (AOA) information measured at both the mobile device and reference device. This information is used to derive line of possible mobile device position (LPMD). The intersection points of LPMDs are used to estimate mobile position. However these algorithms do not work well in a dense multipath environment with high levels of TOA and AOA measurement noise. In addition, these techniques require at least two single bounce reflection paths to locate the mobile position. This paper explores the feasibility of using multiple image theory to obtain the image point of the NLOS single bounce multipath to perform NLOS localization and overcome the abovementioned limitations. Simulation results have shown that there are few variance shape of image point with various combinations of TOA and AOA variance noises. With the discovery of these variance shapes in the image point, it opened up new method and possibility to perform NLOS localization in a more effective and accurate way.

1. INTRODUCTION

Wireless localization is an important area that receives significant research interest recently. It is required in many sensor network applications, such as transportation systems, personal tracking and navigation [1–3]. Conventional LOS schemes fail to work when there are insufficient RDs in LOS with the MD or when the signals are dominated by NLOS paths [4, 5]. Several NLOS mitigation techniques [6, 7] have been suggested to identify and discard NLOS signals. These techniques are, however, will not perform satisfactorily as they generally require the number of LOS RDs to be more than the number of NLOS RDs.

With the popularity of Multiple Input Multiple Output (MIMO) system using antenna array [8, 9], Non Line of Sight localization (NLOS) techniques have been proposed to tackle the problem of insufficiency of LOS path. In NLOS schemes, NLOS information, like those of one bounce scattering, is not discarded but used to complement LOS information in determining MD position. So far, NLOS information that is contained within one bounce scattering paths can be used to assist LOS paths [10, 11]. However, these methods do not work well in environments when multipath becomes too dominant and distances traveled by multiple-bounce reflection paths become comparable with those of one-bounce reflection, causing weighting factors of multiple-bounce LPMDs to be comparable with those of one-bounce. Also, these methods is unable to locate

![Figure 1: Geometrical depiction of the image point RD.](image-url)
MD relying only one signal path and the accuracy will be deteriorated when the TOA and AOA measurement noises become larger.

In this paper, we use multiple image theory to get the image point of NLOS single path reflection path to perform NLOS localization. Most importantly, the concept of image brings the opportunity to improve the robustness and accuracy of NLOS localization. Our simulation results have also shown the shape of image point with various combinations of TOA and AOA variance noises.

2. CONCEPT OF IMAGE POINT

As shown in Fig. 1, RD with known location coordinate \((x_0, y_0)\) has a measured angle \(\theta\) for one bounce scattering path and MD with estimation coordinate \((\hat{x}, \hat{y})\) has a measured angle \(\phi\). The distances measured at RD and MD are equal to \(d\) and \(r\) respectively. \(\sigma_d, \sigma_r, \sigma_\theta, \sigma_\phi\) are the standard deviations of TOA and AOA measured at RD and MD respectively that are followed by Gaussian distribution. From the figure, we can observe that the image point RD\(_I\) is in symmetry with RD with regards to the reflection surface. To calculate the image point RD\(_I\), we can change one bounce scattering path to LOS path. As such, when the MD keeps moving around the environment, through constructing the image point we are able to change multiple bounce reflection paths to single bounce reflection and based on the bidirectional NLOS localization scheme [10], we still can leverage on the multiple bounce reflection paths to do the localization.

To evaluate the performance of our proposed scheme, the following three scenarios will be illustrated:

**Figure 2:** Scatterplot of the estimated image point RD\(_I\). (a) Case A — \(\sigma_d = \sigma_r = 3\) m, \(\sigma_\theta = \sigma_\phi = 6^\circ\). (b) Case B — \(\sigma_d = \sigma_r = 3\) m, \(\sigma_\theta = \sigma_\phi = 2^\circ\). (c) Case C — \(\sigma_d = \sigma_r = 1\) m, \(\sigma_\theta = \sigma_\phi = 6^\circ\).
• Case A. $\sigma_d = \sigma_r = 3 \text{ m}, \ \sigma_\theta = \sigma_\phi = 6^\circ$
• Case B. $\sigma_d = \sigma_r = 3 \text{ m}, \ \sigma_\theta = \sigma_\phi = 2^\circ$
• Case C. $\sigma_d = \sigma_r = 1 \text{ m}, \ \sigma_\theta = \sigma_\phi = 6^\circ$

Measurement data metrics (AOA and TOA) were measured by using ray tracing methodology proposed in [12–14]. One RD was positioned in the environment at (25, 4) and the mobile device was placed at (22.5, 32). There are two signal paths between RD and MD, LOS path and one bounce reflection path.

It is observed from the simulation results, as illustrated in Fig. 2, that the shape of the estimated image point $\text{RD}_I$ is always an ellipse under the above three cases. Thus we are able to make use this character to develop novel method for NLOS localization.

3. CONCLUSIONS

A novel approach to introduce the concept of image for NLOS localization has been proposed. The shape of image was tested and shown to be an ellipse under various conditions. Moreover, by exploring the image we can create new method for NLOS localization.

REFERENCES