Theoretical Examination in Near Filed Object Position Estimation

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***Abstract* – A near field object position estimation method using hyperbolas have been proposed by the authors. This paper clarifies performances of the proposed method by a geometrical optics approximation analysis. In addition, effectiveness of the proposed method is shown by comparison of the approximated analysis results and electromagnetic analysis results.**

***Index Terms* — Array Antennas, Position Estimation, Near Field.**

1. Introduction

Conventional object position estimation methods using a radio wave require a direction finding and a distance measurement in general [1]. However, the direction finding and the distance measurement are difficult in a near field. Therefore, the authors proposed a position estimation method for near field object [2].

This paper clarifies performances of proposed method by a geometrical optics approximation analysis. In addition, effectiveness of the proposed method by comparing the geometrical optics approximation analysis and electromagnetic field analysis is shown.

2. Proposed Object Position Estimation Method

(1) Antenna Configuration in Proposed Method

Fig. 1 shows an antenna configuration and an object. A radiator and receiving elements are arranged linearly with spacing 0.5λ. Number of the array elements is K. It is supposed that the object is placed over the array. The parameter R is the distance between the radiator and the object. The parameter r_k is the distance between the object and k-th element.

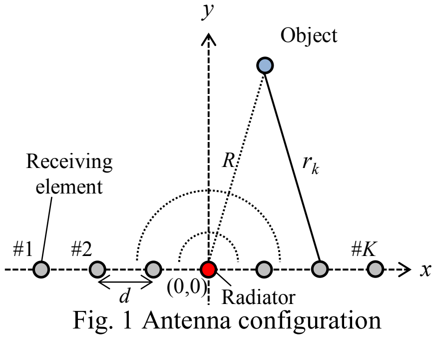


Fig. 1 Antenna configuration

(2) Position Estimation Algorithm

The center element radiates radio wave. The wave is reflected by the object and received by receiving elements. Adjacent two elements are defined as "Element pair". There is a phase difference between the elements according to the distance from the object to each element [3]. Thus, the distance difference between the adjacent elements is obtained from the phase difference. A hyperbola is drawn from the distance difference in the element pair as shown Fig. 2. The object exists on the hyperbola and the intersection position of the hyperbolas corresponds to the position of the object. In the analysis, an asymptote is used instead of the hyperbola in order to simplify. The asymptote is expressed as Eq. (1).

$$y = \frac{\sqrt{d^2 - \Delta r^2}}{\Delta r}(x - p_x) \tag{1}$$

In the real situation, cross points of multiple hyperbolas don't concentrate at a one point due to effects of thermal noise as shown in Fig. 3. Therefore, a barycenter of the intersections is treated as the estimated positon.

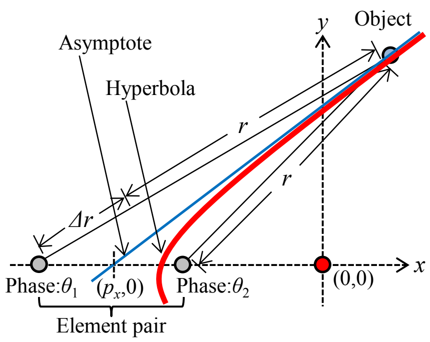


Fig. 2 Hyperbola by phase difference

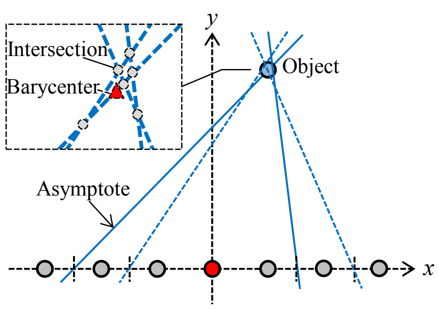


Fig. 3 Hyperbolas and estimated position

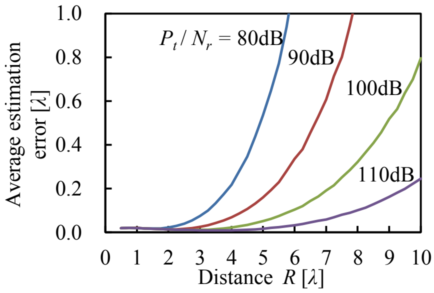


Fig. 4 Effect of P_t/N_r on estimated error

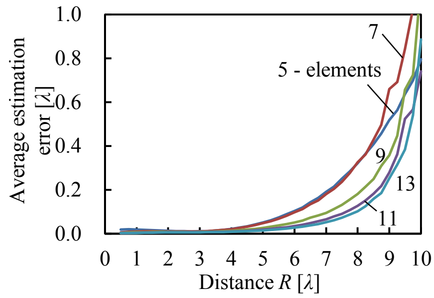
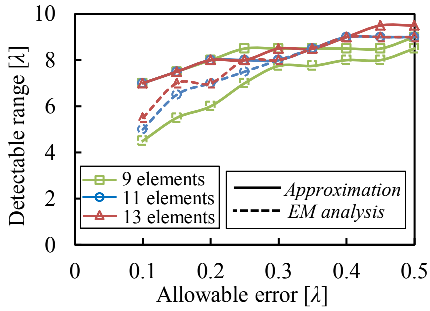
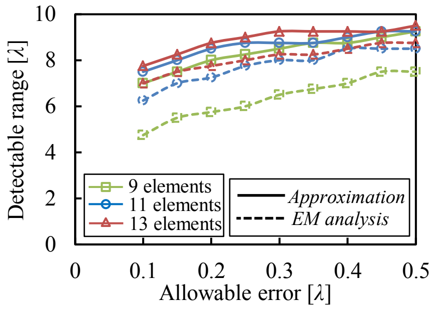


Fig. 5 Effect of number of elements



(a) *x* direction



(b) *y* direction

Fig. 6 Comparison of detectable range

3. Geometrical Optics Approximation Analysis

(1) Effect of Thermal Noise

Fig. 4 shows the effect of thermal noise on estimated error. The horizontal axis represents the distance R, and the vertical axis represents the average estimated error. The parameter in the figure is the P_t/N_r. Here, P_t is the radiating power. N_r is the thermal noise power of receiving antennas.

The number of array elements is 5. The object exists on the y axis. From Fig. 4, if the object exists within 2λ from the radiator, the object position can be estimated within a 0.1λ of estimated error. On the other hand, if the parameter $R > 2\lambda$, the estimated error increases exponentially. This is because SNR of receiving elements is reduced as the distance R increases. The object position can be estimated within 0.8λ estimated error if $P_t/N_r \geqq 100$dB.

(2) Effect of Number of Array Elements

Fig. 5 shows the effect of array elements on estimated error. The P_t/N_r is 100dB. The parameter in the figure is the number of array elements.

From Fig. 5, we can see that the estimated error is reduced as the number of elements is increased. This is because the array length is expanded by increasing the array elements. If the array length is long, the estimation accuracy is improved because the crossing angle at intersection approaches at a right angle. The SNR of elements located at the end of array is reduced if elements are too much. So that estimation accuracy decreases. Therefore, in this method, 13 elements array antenna is suitable.

4. Verification of Effectiveness by Comparison of Analysis Result

Fig. 6 shows the comparison of the approximated analysis results and the electromagnetic analysis results. The horizontal axis represents the allowable error in the estimation, and the vertical axis represents the detectable range. The detectable range is defined as the area that the estimation error is within the allowable error. Fig. 6(a) and (b) shows the maximum length in the detectable range of x-direction and y-direction, respectively.

From Fig.6, there is a difference in the results of the approximation analysis and the electromagnetic analysis if the number of elements is few and the allowable error is small. It is might because of the effects of the calibration error on the electromagnetic analysis. However, we can see that the approximated analysis results and the electromagnetic analysis results indicate a similar tendency. Therefore, the effectiveness of the proposed method was clarified.

5. Conclusion

The performance of the object position estimation in near field was clarified by the geometrical optics approximation analysis. It was shown that the object position could be estimated within 0.8λ of estimated error if $P_t/N_r \geqq 100$dB. Further, 13 elements array antenna was suitable. In addition, the effectiveness of the proposed method was shown by the comparison of the approximation analysis results and the electromagnetic analysis results.

References

[1] S. Warren and T. Gary, "Antenna theory design", J oh n Wiley & Sons, Inc, New York, pp.403-404, 1998.

[2] T. mamiya, M. Fujimoto, T. Hori, T. tabata, S. Hori, "Near field position estimation using multiple antennas and frequencies", Proc. iWEM2014, Hokkaido, Japan, POS1.23, Aug. 2014 .

[3] N. Kikuma, "The adaptive antenna technology," Ohmsha, Ltd., Tokyo, 2003