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Positional Estimation for Micro-Wireless Transmission Internal Device of the Body

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1. Introduction

In the near future, a micro-wireless device inserted inside the body will be an ultimate sensor for the observation of the diseased part directly and the daily health care monitoring. An important issue for this device is to find precise location in real time. This paper presents a precise location measurement method of a wireless device inside the body using array antenna system. The conventional method with DOA estimation can be applied for the receiving antenna array is far enough from the signal source to assume the plane wave incidence [1]. The electromagnetic wave radiated inside the body is refracted and attenuated in propagating inside lossy media, then, it is impossible to use conventional estimation method. In this paper, a novel method is proposed to find the position of the device inside the body taking into the effect of spherical wave incidence, refraction and attenuation and unknown electrical parameters of the media.

2. DOA estimation for spherical wave propagating inside body

Assuming the body as a uniform lossy material, a plane wave E radiated from the device is expressed by the electric field strength E_1 on the boundary between the medium and air, and the propagation constant k as,

$$E = E_1 e^{-jkz'} \tag{1}$$

The taransmission coefficient from the lossy material to the free space is given as,

$$T_{TM} = \frac{2\mu_2 n_{12}\cos\theta_i}{\mu_1 n_{12}^2 \cos\theta_i + \mu_2\sqrt{n_{12}^2 - \sin^2\theta_i}}, \qquad T_{TE} = \frac{2\mu_2\cos\theta_i}{\mu_2\cos\theta_i + \mu_1\sqrt{n_{12}^2 - \sin^2\theta_i}} \tag{2}$$

where n_{12} is a relative index of refraction, μ_1 is magnetic permeability of medium 1, μ_2 is the one of medium 2 and θ_i is an angle of incidence. Denoting the propagation distance in the free space as d', the electric field strength on the x-axis is represented as eq. (3) for TM mode.

$$E_3 = E_1 \times e^{-jkz'} \times T_{TM} \times \frac{\lambda}{4\pi d'} \tag{3}$$

Figure 1 shows the electric field distribution on the observation plane calculated by eq. (3). This is a like Gaussian distribution, then, it is impossible to assume the incident plane wave. In addition, the conventional method using spherical wave assumption is not applied to this model because the refraction and attenuation should be considered [2][3]. Then this paper proposes the DOA estimation with spherical wave considered the influence of the human body. This proposed technique estimates separately the phase difference for the lossy medium and the air, respectively. The mode vector given by the above is calculated using the analysis model as shown in Fig. 2. The phase difference in the lossy media is expressed by the model of Fig. 3.

ISBN: 978-4-88552-223-9 C3055©IEICE

This proposed technique treats separately the phase difference for the lossy medium and the air. Then the mode vector considered of the influence of the human body is calculated. Figure 2 shows the entire simulation model. First, the phase difference in the lossy media is expressed by Fig. 3 as follows.

$$\phi_{1k} = -\frac{2\pi}{\lambda}(\sqrt{R_1^2 + l^2} - R_1) \tag{4}$$

Secondly, the phase difference in the air as shown in Fig. 4(a) is converted to the model of Fig. 4(b) by shifting the equivalent refraction point by l. This compensated phase difference is given as eq. (5).

$$\phi_{2k} = -\frac{2\pi}{\lambda}(\sqrt{R_2^2 + (0.45\lambda - l)^2} - R_2) \tag{5}$$

By using the above equations, the mode vector of spherical wave considering the refraction is represented as eq. (6).

$$a_k(\theta) = E_3\big(\exp\big(-\frac{2\pi}{\lambda}\big(\sqrt{R_1^2 + l^2} - R_1\big)\big) + \exp\big(-\frac{2\pi}{\lambda}\big(\sqrt{R_2^2 + \big(0.45\lambda - l\big)^2} - R_2\big)\big)\big) \tag{6}$$

The above E_3 is given by the equation defined by the eq. (3). The method of finding a location of a wireless device uses the mode vector derived by eq. (6). When relative permittivity, electric conductivity, and depth of target are changed in the estimated range, we extract the depth z by searching the largest peak of MUSIC spectrum as given in eq. (7). Then the target position is obtained by this procedure.

$$P_{MU} = \frac{a^H(\theta)a(\theta)}{a^H(\theta)E_N E_N^H a(\theta)} \tag{7}$$

3. Simulation Results

The simulation parameters are shown in Table 1. We assume that the relative permittivity of human tissues is $\epsilon_{1r} = 10 \sim 60$, the electric conductivity of human tissues is $\sigma_1 = 0 \sim 2$ S/m, and the depth of wireless devices is $z = 0 \sim 10$ cm. As shown in Fig. 1, the TM and TE waves have almost the same performance, we only simulate the TM wave case. In addition, this paper assumes the human body to be a uniform media.

RMSE as a function of snapshots at $z = 5$ is shown in Fig. 5. Input SNR is 10 dB by the broken line and 20 dB by the solid line. RMSE becomes small as the number of snapshots increase for both SNRs. When n is 2000 or more, RMSE is less than 0.1 cm for 20 dB.

Estimation accuracy by the depth of the wireless device is compared at $n = 1000$, where the input SNR is 10 dB and 20 dB. The results are shown in Fig. 6 by the black line. The accuracy is low for the deep position of the device. RMSE exceeds 3 cm at $z = 8$ cm when input SNR of 10 dB and 20 dB. To improve the accuracy, the position of a standard element is changed from the center to the edge as shown in Fig. 7. The maximum value of the accuracy of estimating DOA is improved by 3 cm at $z = 8$ cm as shown in Fig. 6. When the standard position is center, the reception phases received at both ends are the same, then the edge position case extends the effective receiving aperture.

Finally, the estimation accuracy for the input SNR evaluated at $z = 5$ cm is shown in Fig. 8. RMSE for SNR = 20 dB is about 0.9 cm better than for SNR = 0 dB.

4. Conclusion

The purpose of this paper was to find a precise location of wireless devices inside body. Provided we found the position of the maximum electric power, RMSE is 0.07 cm for $n = 1000$, $z = 5$ cm and input SNR of 20 dB. The assumptions used in this paper will be verified by the future measurements and precise simulation model.

References

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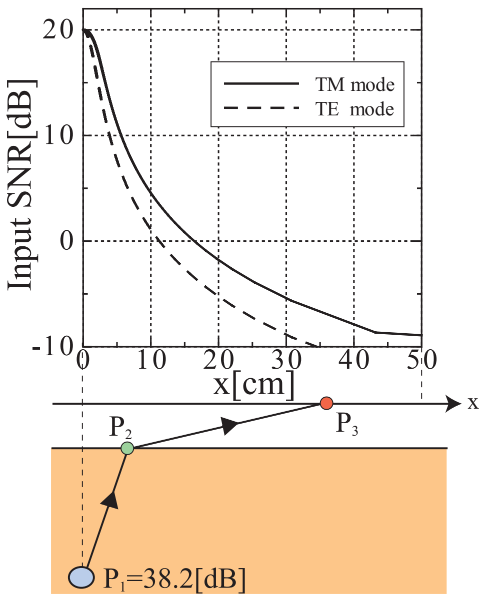

Fig. 1: Received power on x axis

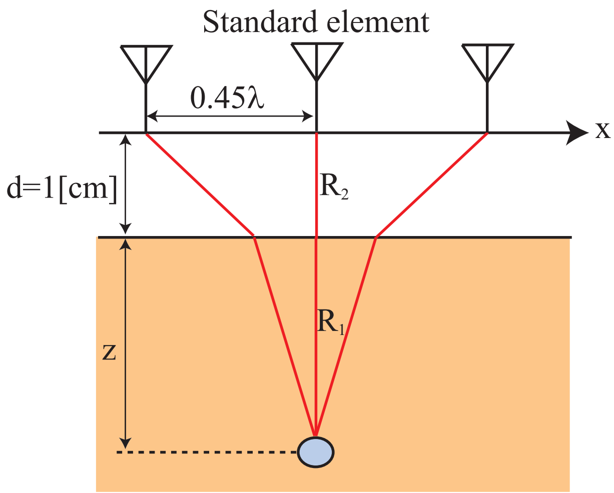

Fig. 2: Propagation path from source to observation plane

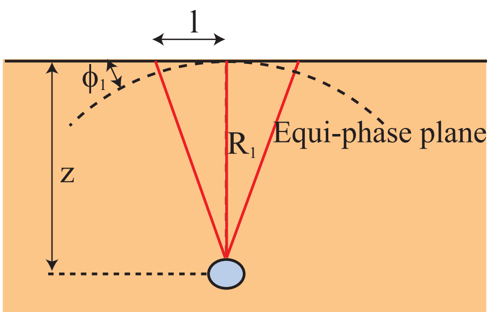

Fig. 3: Propagation inside the body

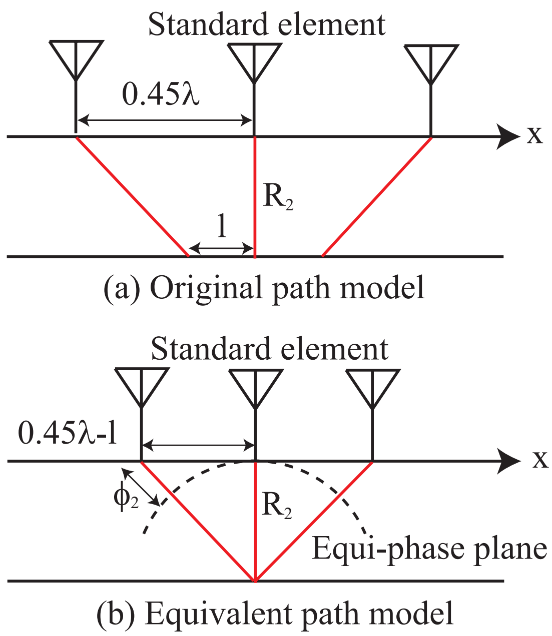

Fig. 4: Propagation path

Table 1: DOA simulation parameter

Number of element	3
Incident wave	TM, 1 wave
Distance between elements	0.45λ
Relative permittivity of body	40
Electric conductivity of body	1.8[S/m]
Transmission frequency	2.4[GHz]
Thickness of air layer	1[cm]
Number of estimation	50 times

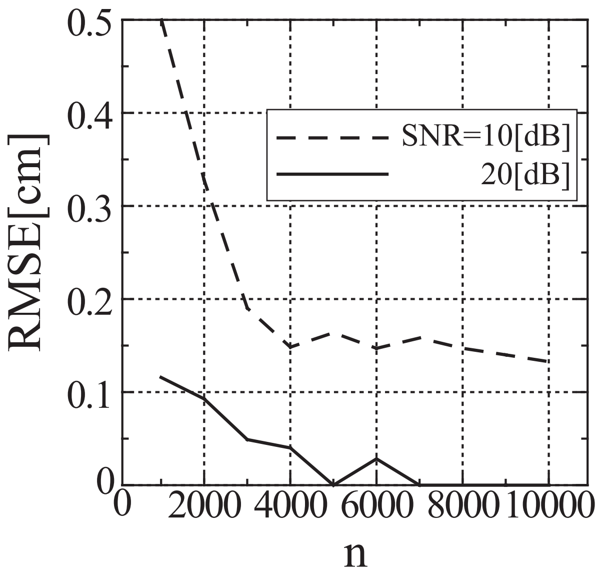

Fig. 5: RMSE as function of snapshots

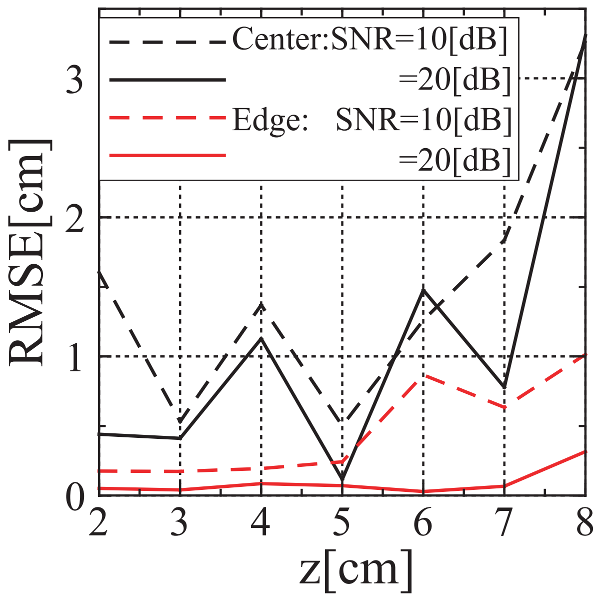

Fig. 6: RMSE as a function of z

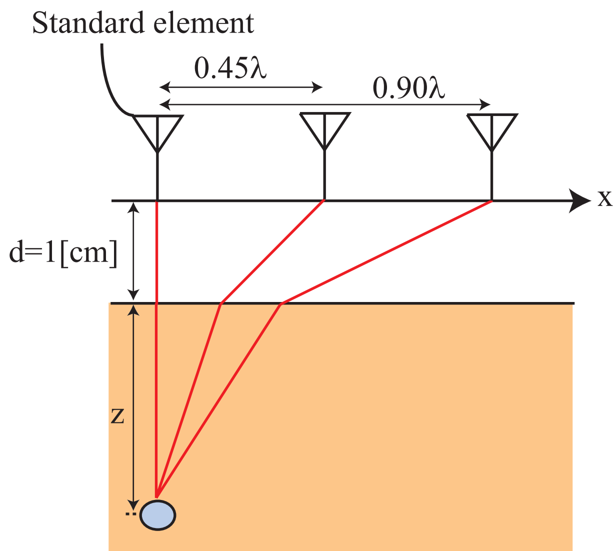

Fig. 7: Standard element at left edge

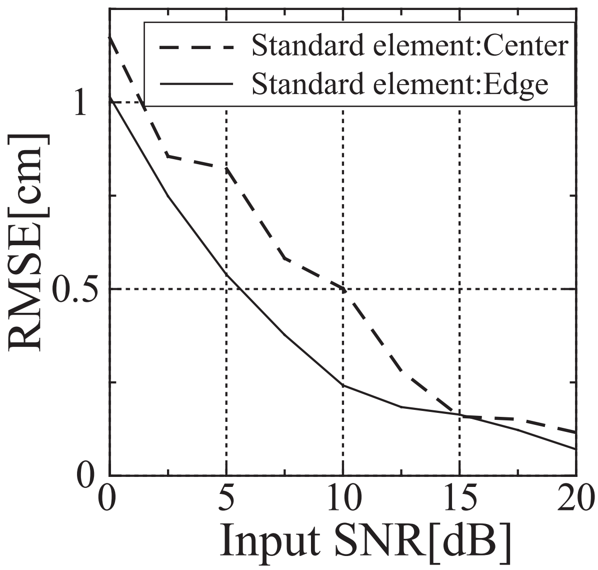

Fig. 8: RMSE as a function of SNR at z=5[cm]