Shadowing Analysis of a BAN Diversity Antenna Based on Statistical Measurements of the Human Walking Motion

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1. Introduction

In body area network (BAN) systems, BAN radio devices, such as sensors or access points used for data collection and sending, may be mounted on the waist. The shadowing effects caused by the movement of the arms result in a further severe gain reduction [1]. It is anticipated that the moving characteristics of the arms have a number of differences unique to individual humans, such as asymmetrical distribution. However, the dynamic characteristics, such as swing style and speed, and walking pace and cycle, were not fully examined in previous studies. Hence, a typical canonical model to represent the walking motion was used in the analysis of BAN shadowing properties [2].

This paper presents the shadowing analysis of a BAN diversity antenna based on statistical measurements of the human walking motion. Firstly, the dynamic characteristics of the arm swing motion were measured using a number of test persons, and then the statistical analysis was carried out using the measured data to extract useful knowledge used for the analysis of BAN antennas, such as the average angle and standard deviation. Secondary, the analytical results are shown on the shadowing effects of a BAN diversity antenna based on the statistical data of the swing motion.

2. Measurements of the Walking Motion

In the first step of our study, a series of video recording was carried out when a person walks in a natural way of swinging over a 7-meter walking distance in a typical classroom of the Toyama university using thirteen 22 to 25-year-old Japanese males. Since our goal is to analyse a BAN diversity antenna mounted on the waist, we focus on the swing motion of the right and left arms although the measured video data include numerous information about the walking pace, cycle, and so forth. The right and left arms are recorded separately for good visibility of the swing motion.

As shown in Fig. 1, the maximum swing angle $\alpha_m$ is defined as the angle indicating that the plus sign means that the arm swings in the forward direction with respect to the human body. Fig. 2 shows a snapshot of the walking motion. As can be seen from Fig. 2, the maximum swing angle $\alpha_m$ is measured to be 38.8 deg. in the forward swing direction, and -13.8 deg. in the backward direction.

Fig. 3 shows the probability distribution of the maximum swing angle of the left arm. The Gaussian distribution defined by Eq. (1) is also plotted in the figure for comparison using the average value $\mu$ and the standard deviation $\sigma$.

$$f(\alpha_m) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(\alpha_m - \mu)^2 / (2\sigma^2)}$$  (1)

It can be seen from Fig. 3 that the measured results agree well with the Gaussian distribution and spread over the entire angular region, equivalent to a large standard deviation, indicating that there is a significant difference in the walking style among individual humans.

Table 1 summarizes the minimum, maximum, average and standard deviation extracted from the whole of the video recording data. It can be seen from Table 1 that there is a small asymmetry between the maximum swing angles of the right and left arms. In contrast, Table 1 also shows that there is a large asymmetry between the swing angles in the forward and backward directions.
3. Analytical Model of the Diversity Antenna

Fig. 4 illustrates the analytical model used for the method of moments [2]. The head and body are approximated by circular cylinders, the dimensions of which are 18 cm in diameter by 25 cm in height, and 22 cm in diameter by 140 cm in height, respectively. The right and left arms are also approximated by circular cylinders, the dimensions of which are 8 cm in diameter and 60 cm in length. The distance (gap) between the surface of the arms and the body is 3 cm. As shown in Fig. 4, the angle $\alpha$ is defined as the instantaneous swing angle of the arms.

A diversity antenna, comprising two half-wavelength dipole antennas in the vertical orientation, was mounted on the left waist in the symmetrical configuration with respect to the center of the left arm. The electrical properties of the model are chosen such that the relative permittivity is 55.8 and conductivity is 0.99 S/m, which are the average values for human muscle at 950 MHz.

As mentioned in the previous section, there is a significant difference in the walking style among individual humans. Hence, in this paper, the analysis is carried out by adopting the average values as the maximum swing angle $\alpha_m$ of the right and left arms, as depicted in Table 1; $\alpha_m = +40$ deg. in the forward direction, and $\alpha_m = -15$ deg. in the backward direction.

4. Results and Discussions

Fig. 5 shows the radiation patterns in the horizontal plane as a function of the angle of the left arm with the location of the diversity antenna being $\phi_1 = 80$ deg. and $\phi_2 = 100$ deg at 950 MHz. An inset drawn in the figure exhibits the geometrical relationship between the diversity antenna and the left arm when the model is facing to the right. Fig. 5(a) exhibits the case where both of the branch antennas are located behind the left arm, and there is a significant reduction in the radiation patterns for both of the branches #1 and #2, meaning that they function poorly as a diversity antenna. In Fig. 5(b), only the branch #1 is located behind the left arm, and hence severe gain degradation can be seen only for the radiation pattern of the branch #1, implying that they function effectively as a diversity antenna. In Fig. 5(c), both of the branches appear out of the left arm, and thus there is little degradation for both of the radiation patterns, and in this case, the diversity function is not required.

Fig. 6 shows the radiation efficiency as a function of the angle of the left arm $\alpha$ when the location of the diversity antenna is varied around the surface of the human body. In Fig. 6, the angle $\phi$ is defined as the angle indicating the location of the dipole antenna, as shown in Fig. 4, in which the two curves with the same symbols mean that they comprise a single diversity antenna. It can be seen from Fig. 6 that in the case of $\phi_1 = 80$ and $\phi_2 = 100$ degree, the radiation efficiency falls below -14 dB when the left arm approaches the dipole antennas. In the case of $\phi_1 = 50$ and $\phi_2 = 130$ degree, the diversity antenna effectively function, since one of the branches has a good radiation efficiency.

Fig. 7 shows the diversity gain $G_d$ as a function of the antenna separation ($\Delta \phi = \phi_2 - \phi_1$). The selection diversity is used as a combining method. The diversity gain is defined as the ratio of the radiation efficiency of a diversity antenna under consideration to that of a single dipole antenna located at $\phi = 90$ deg. It can be seen from Fig. 7 that the diversity gain of greater than 12 dB is obtained when the separation of the diversity antenna exceeds 80 deg.

Fig. 8 shows the power imbalance as a function of the angle of the left arm $\alpha$. In Fig. 8, the same symbols are used as in Fig. 6. The power imbalance is defined as the ratio of the radiation efficiency of the two dipole antennas. It can be seen from Fig. 8 that the power imbalance of approximately 8 dB is given when $\phi_1 = 50$ and $\phi_2 = 130$ deg. Fig. 8 also shows that when the separation of the two branches is increased, the power imbalance is reduced to 2 dB.

It is found from Fig. 7 that the antenna separation of greater than 80 deg. is required for reducing the shadowing effects. However, Fig. 8 shows that the power imbalance of 8 dB is given in this situation. In this paper, we focus on the evaluation of shadowing with the absence of reflected waves coming from the surrounding objects. However, in actual uses scenarios, BAN radios are used in a multipath environment, meaning that the diversity effect may be degraded due to the power imbalance. It is concluded from these discussions that BAN radios should be designed considering both shadowing and multipath effects, and this will be addressed for our future studies.
5. Conclusion

This paper presents the shadowing analysis of a BAN diversity antenna. From extensive studies, a number of important observations and physical quantities unique to BAN applications have been described and will prove helpful in actual system design.

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References


Table 1 Measured results of the maximum swing angle

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<th>Swing Status</th>
<th>Min</th>
<th>Max</th>
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<th>σ</th>
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<td>Left arm (forward) +α_m</td>
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Fig. 1 Definition of the angle α_m

Fig. 2 Snapshots of the walking motion of a human

Fig. 3 Probability distribution of the maximum swing angle α_m of the left arm
Fig. 4 Analytical model of the diversity antenna

Fig. 5 Radiation pattern vs. angle of the left arm
(a) $\alpha = 0$ deg.
(b) $\alpha = 5$ deg.
(c) $\alpha = 20$ deg.

Fig. 6 Radiation efficiency vs. angle of the left arm

Fig. 7 Diversity gain vs. antenna separation

Fig. 8 Power imbalance vs. angle of the left arm