Measurement of capsule endoscopy position with the transmitting and receiving antennas for WPT

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Abstract: In recent years, a capsule endoscopy has been used as a medical device to diagnose small intestines painlessly. Wireless power transmission (WPT) to the capsule endoscopy has been studied. The efficiency of WPT can be improved by using location information of the capsule. In the previous research, a localization method for the WPT was developed in simulation. In the present paper, we evaluated the localization algorithm developed in the previous research by measurement, so that the effectiveness of the algorithm was demonstrated.

Keywords: Capsule endoscopy, Position estimation, Received signal strength, Wireless power transmission

Classification: Antennas and propagation

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1 Introduction

In recent years, a capsule endoscopy has been used as one of the medical devices that can diagnose small intestines and large intestines. A capsule endoscopy is a capsule type medical device that takes images in the digestive tract and wirelessly transmits the image data to the outside of the body. One of the problems of the capsule endoscopy is the drive source. The drive source of the capsule endoscopy is the only built-in battery, and therefore, the drive time and the number of the images are restricted. Moreover, electrolyte solution leaking from the battery can affect human health if the capsule is damaged in the body. In order to solve these problems, wireless power transmission (WPT) to the capsule endoscopy is considered [1].

We arrange the transmit antennas in an array and control the phases, so that the radiation directivity can be controlled [2]. Focusing the beam on the capsule is expected to improve the efficiency of the WPT. The localization of the capsule endoscopy is required in order to focus the beam on the capsule.

Localization using received signal strength (RSS) utilizes only the RSS collected in the communication without additional electric energy and an additional bandwidth [3]. Therefore, the localization technology using RSS can be applied to the localization in the body [4]. The localization in the body require a high calculation cost due to complicated calculation considering the human body [5]. In order to apply the localization to the WPT, a short calculation time for the localization is required. Many localization algorithms were developed with nondirectional electromagnetic waves radiated from the antennas. The WPT technology uses microwaves. We supply electric power with the antennas [6]. Therefore, the capsule endoscopy is localized with the transmitting and receiving antennas for the WPT. The magnetic field of the cylindrical magnet in the capsule endoscopy was measured for localization of the capsule. However, this research was conducted in the air, and the human body was not considered [7].

In the previous research, a simple algorithm considering the directivity of transmitting and receiving antennas with the RSS was developed in simulation for
the purpose of localizing the capsule during examination [8]. The purpose of the present paper is to investigate whether the localization method of the previous research can be applied to the localization of the capsule with the transmitting and receiving antennas for the WPT. Therefore, we evaluated the localization algorithm in the previous research by measurement, and we confirmed the effectiveness of the algorithm.

2 Localization method

We localize the capsule with the simple abdomen model of the cuboids consisting of fat and muscle. Target values of electric constant in each tissue are muscle ($\varepsilon_r = 57.7$, $\sigma = 0.83$ S/m) and fat ($\varepsilon_r = 11.6$, $\sigma = 0.08$ S/m) at 433.92 MHz. The muscle which is most of the simple abdomen model is often employed in basic studies on electromagnetic waves related to the human body. Therefore, as a preliminary step toward the study on a complicated human body model, the simple abdomen model is reasonable. We also adopt 433.92 MHz in UHF band for the WPT and communication due to applying the same antennas to the WPT and data communication. The localization model is shown in Figure 1. The four receiving antennas are stuck on the human abdomen, and the transmitting antenna is arranged in the localization area imitating the small intestine area. We move the transmitting antenna to 147 localization points in the localization area, and measure the four RSSs deriving from the four receiving antennas. The localization points are also arranged at 30 mm intervals. The 30 mm interval is smaller than the target value of the localization error of 40 mm. Therefore, the localization can cover the entire localization area.

We employ the same localization algorithm as the previous research [8]. The difference between the estimated position and the capsule position is defined as the localization error. The localization method is evaluated by the localization error.

![Localization model](image)

Fig. 1. Localization model

3 Experiments for localization

A measurement system is shown in Figure 2 (a). The transmitting and receiving antennas connect with a network analyzer (Agilent, N5230C, PNA-L). The transmission and reception of the power are via the phantom of the simple abdominal model. The measurement procedure is as follows. First, the power
transmission port of the network analyzer supplies the electric power to the transmitting antenna. Second, the transmitting antenna radiates a radio wave in the phantom of the simple abdominal model, and the receiving antenna receives the radio waves. Third, the S21 is measured with the network analyzer. Finally, This S21 is adopted as the RSS in the localization. We use an amplifier and attenuator to increase the output power of the network analyzer by 10 dB. The output power is amplified to prevent the received power in the network analyzer from falling below the level that can be processed by the network analyzer. Styrofoam boxes are adopted to keep the shape of the simple abdomen model phantom. The styrofoam boxes are also applied as the spacer supporting the simple abdominal model. The simple abdomen model phantom is glycerin phantom, and consists of the liquid muscle phantom \( (\varepsilon_r = 57.5, \sigma = 0.83 \text{ S/m}) \), the plastic bag, the solid muscle phantom \( (\varepsilon_r = 57.8, \sigma = 0.81 \text{ S/m}) \) and the solid fat phantom \( (\varepsilon_r = 10.6, \sigma = 0.08 \text{ S/m}) \) at 433.92 MHz. In the simulation, the capsule was localized with the simple abdomen model by the FDTD method.

We localize the capsule by the radio wave radiated from the capsule. In this localization, a helical antenna in the capsule inside the body was used as the transmitting antenna and a spiral antenna on the body surface was used as the receiving antenna [9]. The helical antenna is the magnetic antenna receiving constant electric power in the communication through the human body. The broadband spiral antenna can stably transmit the electric power to the capsule endoscope moving and rotating in the body. The space inside the capsule endoscope is limited. The helical antenna inside the capsule can transmit images and receive power. The transmitting antenna in the measurement is shown in Figure 2 (b). The reflection coefficient is shown in Figure 2 (c), and has the same good performance as the analyzed value at 433.92 MHz. The material of the transmitting antenna is acrylic \( (\varepsilon_r = 2.9, \sigma = 0.06 \text{ S/m}) \) at 433.92 MHz. The receiving antenna is also shown in Figure 2 (d). The four receiving antennas are employed in the localization. The reflection coefficients of the receiving antennas are shown 2 (e). The reflection coefficients support a wide band around 433.92 MHz and have good performance. The transmitting antenna fixed in the liquid muscle phantom and the measurement of the localization was performed as shown in Figure 2 (f). An acrylic plate is also adopted to fix the transmitting antenna. The receiving antennas fixed in the styrofoam are shown in Figure 2 (g).
The distance in the y-axis direction from the surface of the receiving antenna is defined as the distance in the depth direction. A total of 147 localization points are evenly divided into three depths. The distance in the depth direction is divided into three depths of 50 mm, 80 mm, and 110 mm. As a part of the localization results in simulation and measurement, the localization results in the 80 mm depth are shown in Figure 3. The localization error is defined as a position difference between the transmitting antenna position and the localized position. We compared simulated values with measured values in 147 points with the localization error. The target value of the localization error is within 40 mm. The evaluation criteria of 40 mm is enough for the system requirement of the WPT. 60 mm is also a reference value to see if the estimated position is too far from the capsule endoscope. The number of localization points with localization error within 40 mm...
are 141 (96 %) in simulation and 134 (91 %) in measurement. The differences in the performance of the four receiving antennas resulted in slight differences between the simulation and measurement results. Therefore, the previous localization method using RSS is effective for the localization of the capsule endoscopy with the transmitting and receiving antennas for the WPT.

**Fig. 3.** Localization result

### 5 Conclusion

In this study, we experimentally validated a previously proposed location estimation algorithm for WPT. We move the transmitting antenna to 147 localization points in the localization area imitating the small intestine. The simple abdomen model including the localization area is also employed in the localization model. We evaluated the localization algorithm by the localization error. As a result, the number of the localization points with localization error within 40 mm are 134 (91 %) in simulation and 141 (96 %) in measurement. Therefore, the localization method from the previous research can be adapted to the localization of the capsule endoscopy with the transmitting and receiving antennas for the WPT. In future work, we will improve the accuracy of the localization. We will also localize the capsule with a complicated model simulating an actual human model.

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