

A Feasibility Study of microwave respiration monitoring by off-body sensor

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Abstract. This paper primarily discusses the feasibility of utilizing microwave for monitoring the deflated and inflated states of the lungs during respiration, as well as investigating the influence of system parameters related to off-body sensor. According to the body feature parameter of humans, a two-dimensional model of the human thorax cross-section is constructed. Nine sensors were arranged in the front of the thorax cavity in the form of a line. The frequencies of 433MHz and 915MHz are adopted and each antenna works as transmitter in turn while the other antennas serve as receivers. Preliminary results evaluate the feasibility of monitoring respiration with off-body sensors. At the same time, we used the off-body sensors to explore the influence of each parameter on microwave respiration detection under different frequencies of microwaves by changing the system parameters.

Keywords: Human respiration monitoring, Off-body sensor, Feasibility study.

1. Introduction

Healthcare remains one of the most pressing challenges facing the world today. In recent years, microwave technology has been developed and widely used in the medical field [1]. The application of the microwave in the lung mainly focuses on the monitoring of the respiratory rate and lung imaging analysis.

At present, Doppler radar sensors are commonly used for non-contact medical monitoring [2],[3], and non-contact sensors are often used for the detection of heart rate and respiratory rate. Such monitoring can be done without direct contact with the skin, which is more suitable than traditional methods such as respiration belts [4]. Moreover, because of its comfort, it is more suitable for long-term respiratory monitoring, and it is often used for nighttime monitoring during sleep [5],[6]. At the same time, due to the non-contact characteristics of this method, we can use microwaves with specific frequencies to conduct vital signs detection at a long distance, which can detect the living bodies under the ruins after the disaster [7]. The signal emitted by the off-body sensor has high loss when entering the human body, so there are few studies on the use of non-contact sensors for monitoring imaging.

In the field of surveillance imaging, the commonly used and mature medical imaging technologies are positron emission tomography (PET), magnetic resonance imaging (MRI), computed tomography (CT) and X-ray examination. They are also used in lung imaging to check the health of the lungs [8]. However, the devices using these techniques are generally large and cannot be applied to follow type monitoring for a long time. So people choose to use microwave to replace[9], and now there are a lot of studies on microwave monitoring. For example, Muhammad Azlan et al. demonstrated the feasibility of using a mobile broadband microwave system to scan the torso to detect lung fluid and were able to use microwave imaging technology to detect lung effusion [10]. Didem Ertek et al. believe that microwave imaging systems have the potential to be a cost-effective and less dangerous alternative to conventional medical imaging techniques, and they have studied a microwave imaging protocol to detect pulmonary edema and hemorrhage [11]. Xiaoyou Lin et al. even verified the feasibility of microwave medical imaging to detect COVID-19 [12].

We often choose contact sensors (direct contact with the skin) for microwave imaging monitoring. Such measurements can reduce the loss of microwaves, but the motion of the human torso affects the

sensor and affects the monitoring. We want to reduce the effect of human torso movement on the sensor, so we want to perform microwave monitoring by non-contact sensors.

In order to simplify the problem, this paper assumes that the volume of the lung is constant, but the proportion of gas in the lung will change during the breathing process, which will make the permittivity and conductivity of the lung different [13],[14],[15]. Using this feature, we use different dielectric properties to represent the states of lung relaxation and lung contraction. Different dielectric properties can affect microwave propagation, and this difference can be used in microwave imaging [16],[17]. In this study, COMSOL Multiphysics was used to build a 2D model of the cross-section of the human thorax with a row of off-body sensors placed in front of the body. After setting the parameters of the sensor system each time, each sensor is made to act as a transmitter in turn, and the rest is used as a receiver to receive the information of the transmitter. The microwave frequency of the transmitter was chosen to be 433MHz or 915MHz, and the sensitivity analysis was carried out by using the electric field amplitude values obtained under different parameters to initially evaluate the feasibility of the in vitro sensor to monitor respiration.

2. Dielectric properties of each tissue:

The most important thing to do to model and simulate it numerically is to get the dielectric properties of the tissues. This paper mainly refers to the formula and data published by C. Gabriel [14], and uses MATLAB to draw the corresponding dielectric characteristic curves under microwaves of different frequencies in various materials, as shown in Fig.1:

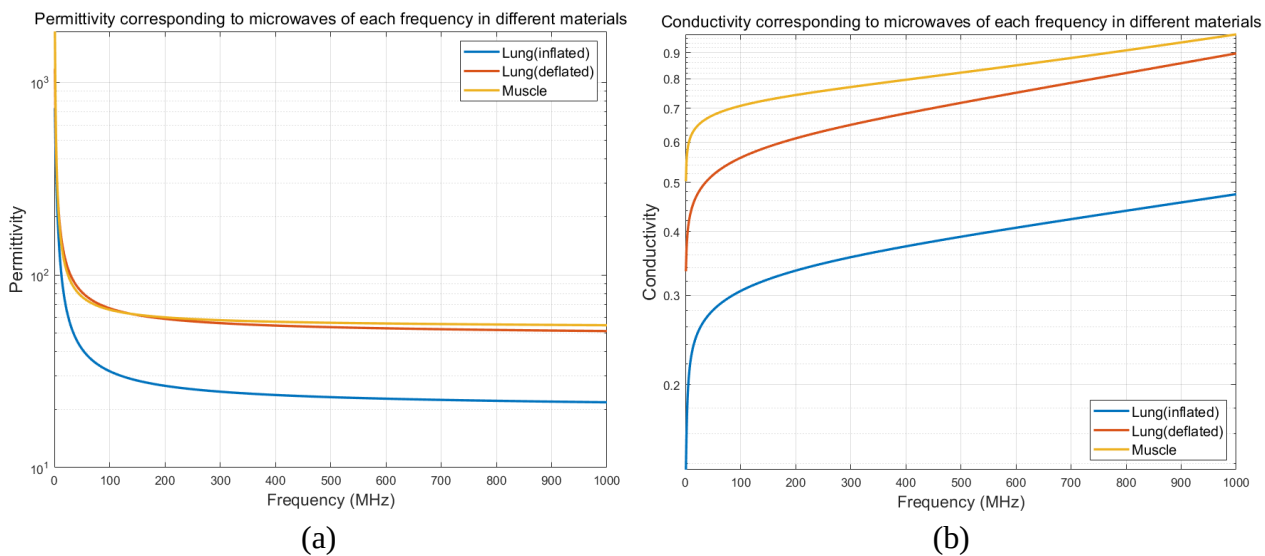


Fig. 1 Dielectric characteristic curves obtained by propagation of microwaves with different frequencies in different materials: (a) Permittivity corresponding to microwaves of each frequency in different materials; (b) Conductivity corresponding to microwaves of each frequency in different materials.

This study finally selected 433MHz as the relatively low-frequency microwave and 915MHz as the relatively high-frequency microwave for data simulation research[18],[19]. According to the drawn image, the dielectric properties of each material are read out, and Table 1 is sorted out as follows:

Table 1 Dielectric properties of materials

	ϵ_r		σ (S/m)	
Frequency	433MHz	915MHz	433MHz	915MHz
Lung(inflated)	23.586	21.9722	0.3799	0.4593
Lung(deflated)	54.198	51.3799	0.6945	0.8637
muscle	56.8732	54.997	0.8049	0.9481

3. Numerical modeling

In this paper, we choose to research a two-dimensional plane. We need to construct a simple model of the cross-section of the thorax and simulate the breathing state of human beings by changing the dielectric properties of the material. For simplicity, the thoracic cross-section model is represented by an ellipse with major half-axis $a_1 = 15\text{cm}$ and minor half-axis $b_1 = 12\text{cm}$. On this basis, the combination of two ellipses with major half-axis $a_2 = 8\text{cm}$ and minor half-axis $b_2 = 5\text{cm}$ is used to represent the section of the lung [17], as shown in Fig. 2. At the same time, each part of the material is specified: assuming that the tissue between the chest wall and the lung is all muscle, the dielectric properties of this part of the material are represented by the permittivity and conductivity of the muscle; The tissue-material dielectric properties of the lung are divided into permittivity and conductivity in the inflated and deflated states of the lung. The above dielectric properties can be read from Table 1. After the thoracic cross-sectional model was constructed, a row of antennas (nine in total, labeled from 1 to 9 from left to right) were placed at a distance of $d_1 = 5\text{cm}$ in front of the chest, and the distance between them was $d_2 = 4\text{cm}$ as shown in Fig. 2 (b). Finally, an airfield with an upper side length of $a_3 = 50\text{cm}$ was added to the periphery of the model, and the scattering boundary condition was set at the edge of the airfield.

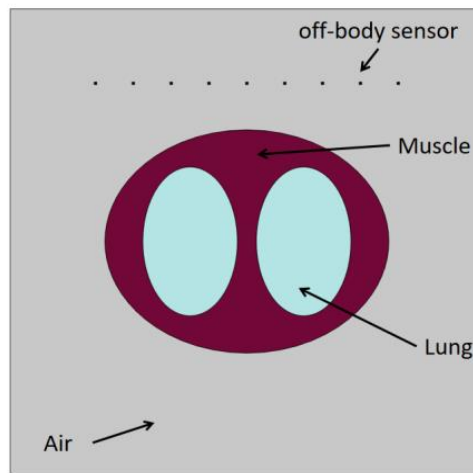


Fig.2 A simple two-dimensional model of the thorax

In each simulation, every antenna has to act in turn as a transmitter, which is to apply a line current source perpendicular to the straight plane. At this time, the other eight antennas without added line current sources are used as receivers for data recording. We changed the system parameters of the sensor and repeated the simulation using 433MHz or 915MHz microwave: The first group made the value of $d_2 = 4\text{cm}$ unchanged and only changed the value of d_1 , which could be selected as 1cm, 2cm, 5cm, 8cm and 10cm. The second group fixed $d_1 = 5\text{cm}$ and only changed d_2 , which could equal to 2cm, 4cm, or 6cm.

To study whether the chest is sensitive to sensor signals in different states of human lung respiration, a factor to quantify this sensitivity is prescribed to describe the changes in the middle of the breathing process. When antenna n acts as a transmitter, the sensitivity factor at antenna m is defined as follows.

$$S_m^n = \frac{|R_m^n - C_m^n|}{(R_m^n + C_m^n) / 2} \quad (1)$$

R_m^n represents the value received by antenna n as the transmitting source and antenna m in the state of lung relaxation, and C_m^n represents the value received by antenna n as the transmitting source and antenna m in the state of lung contraction. In a simulation, after specifying the values of d_1 and d_2 , antenna m is selected as the transmitter to obtain the corresponding sensitivity. The specific operation

is as follows: calculate the sensitivity of other receiving antennas according to equation (1), and then take the average value of these values, denoted as S_m . The average is calculated by adding all the S_m 's and is defined as the average sensitivity denoted as $\bar{S}$.

Let us first explore the impact of different values of d_1 on the sensitivity, and first use 433MHz microwave in the simulation. The value of d_2 is fixed to be equal to 4cm, and the value of d_1 is changed to obtain the value of S_m at each value of d_1 according to the above method. All the values are visualized as shown in Fig.3 (a). The above operations were repeated with 915MHz microwave to obtain Fig.3 (b), and the data were processed to calculate the average sensitivity as shown in Table 2. Then we studied the influence of different values of d_2 on the sensitivity. During this simulation, the value of d_1 was 5cm, and the S_m values corresponding to each d_2 value were obtained by using microwaves of different frequencies. Fig.3 (c) and Fig.3 (d) were plotted and the corresponding average sensitivity was calculated and recorded in Table 3.

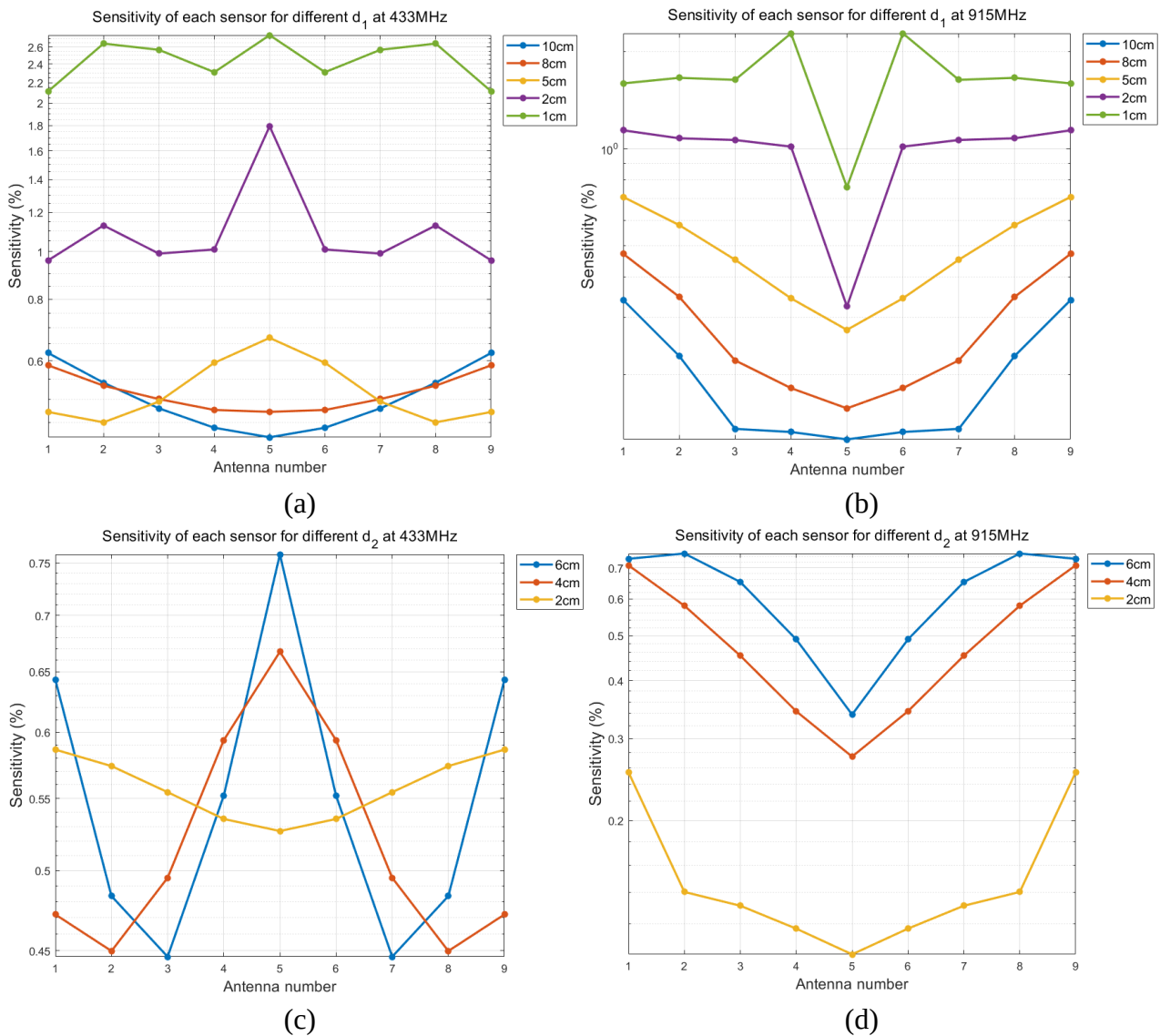


Fig.3 S_m values under different parameters: (a) Using 433MHz microwave and only changing d_1 without changing d_2 ; (b) Using 915MHz microwave and only changing d_1 without changing d_2 ; (c) Using 433MHz microwave and only changing d_2 without changing d_1 ; (d) Using 915MHz microwave and only changing d_2 without changing d_1 .

Table 2 Average sensitivities corresponding to each d_1 when d_2 is identical

d_1 frequency	1cm	2cm	5cm	8cm	10cm
433MHz	2.445%	1.107%	0.521%	0.519%	0.509%
915MHz	1.674%	0.990%	0.494%	0.289%	0.200%

Table 3 Average sensitivities corresponding to each d_1 when d_2 is identical

d_2 frequency	2cm	4cm	6cm
433MHz	0.559%	0.521%	0.557%
915MHz	0.154%	0.494%	0.621%

From Fig.3, we can observe that changing the value of d_1 or d_2 will make the sensitivity curve different. To study these differences more simply and intuitively, we calculated the average value of sensitivity under each condition from the above data and recorded it in Table 2 and Table 3. It is known that the breathing process causes changes in dielectric properties, and the feedback received by the receiving sensor is different even if the transmitting sensor emits the same signal under the same conditions. There is a sensitivity difference, and this difference is the key to imaging. By comparing the measured data of the contact sensor [17], we found that the sensitivity of the non-contact sensor was smaller. The explanation is as follows: in the contact measurement, the microwave directly enters the human body without being reflected and does not propagate in the air, while in the non-contact measurement, part of the microwave will reflect and propagate in the air when it propagates to the human body, resulting in some loss of microwave and thus affecting the microwave propagation process after entering the human body. In order to verify the above conclusions, we plotted the electric field maps of the thorax under different respiratory states when $d_1=5\text{cm}$ and $d_2=4\text{cm}$, the microwave frequency of 433MHz or 915MHz was emitted by sensor 5 (Fig. 4).

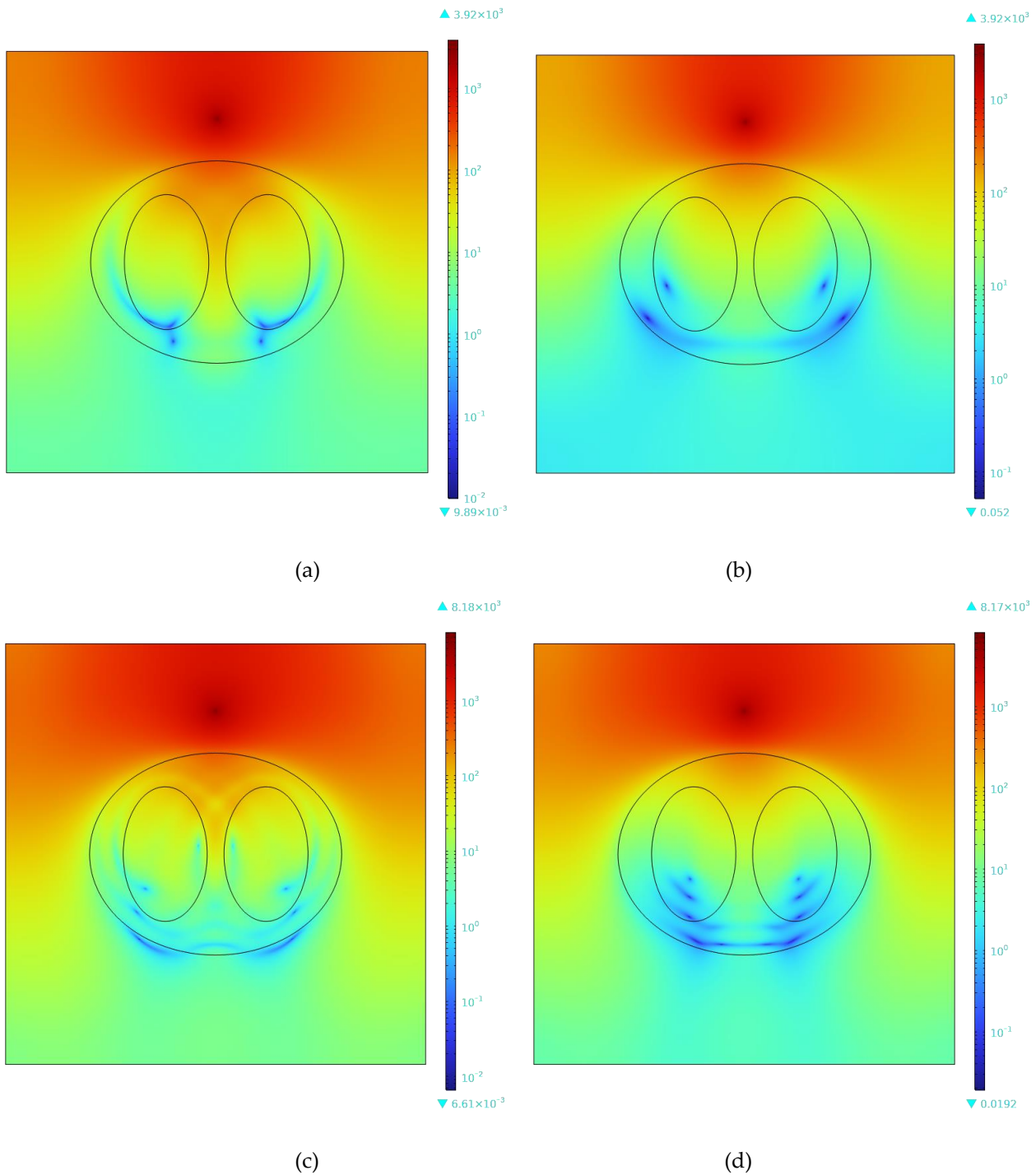


Fig.4 Electric field pattern: (a) Chest electric field map of 433MHz microwave propagation in the inflated state; (b) Chest electric field map of 433MHz microwave propagation in the deflated state; (c) Chest electric field map of 915MHz microwave propagation in the inflated state; (d) Chest electric field map of 915MHz microwave propagation in the deflated state.

According to Table 2, we can explore the law presented when only d_1 is changed and the remaining parameters are unchanged: we find that the larger d_1 is, the lower the sensitivity is. We consider that transmitting microwaves with the same frequency and making the antenna spacing (d_2) constant, the larger d_1 is, the farther the microwave propagates in the airfield, the greater its loss will be, and finally the measured feedback data will be affected. We can find that the sensitivity obtained by transmitting microwaves at the frequency of 433MHz is greater than that obtained by 915MHz under the same conditions. We believe that the reason for this phenomenon is: in general, the higher the frequency of microwaves, the shorter the wavelength, the faster the propagation speed in the medium, but also

will be more reflection and attenuation, so they are more sensitive to the reflection and scattering of obstacles. This leads to excessive microwave loss after 915MHz microwave contact with the human body, making the final signal reflected in the lung too weak.

According to Table 3, we find that for 433MHz microwaves, the change of spacing does not have a great impact on its sensitivity. However, for 915MHz microwaves, the change of the spacing has a great influence on the change of the sensitivity. In this paper, it is believed that this is due to the shorter wavelength of high-frequency microwaves so that a small change in spacing causes a large change in sensitivity.

4. Conclusions

In this work, a pulmonary respiration model is constructed and simulated numerically. The sensitivity is calculated by simulation, and the sensitivity verifies that the method of detecting lung respiration with microwave is feasible. In further study, we simulated by changing the parameters of the sensor and the frequency of the experimental microwave, and it can be found that the corresponding sensitivity difference varies under different parameters. Considering the development of microwave monitoring in modern medicine, we believe that it is feasible to develop a non-contact instrument using the microwave to monitor lung respiration. The parameters and microwave frequencies, which are discussed in the article, also provide reference data for the manufacture of the instrument.

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