

# A TOA based Positioning Technique of Medical Implanted Devices

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## Abstract

*Wireless communication devices in the field of medical implant, such as cardiac pacemakers and capsule endoscopes, have been studied and developed to improve healthcare systems. Especially it is very important to know the range and position of each device because it will contribute to an optimization of the transmission power. We adopt the time-based approach of position estimation using ultra wideband signals. However, the propagation velocity inside the human body differs in each tissue and each frequency. Furthermore, the human body is formed of various tissues with complex structures. For this reason, propagation velocity is different at a different point inside human body and the received signal so distorted through the channel inside human body. In this paper, we apply an adaptive template synthesis method in multipath channel for calculate the propagation time accurately based on the output of the correlator between the transmitter and the receiver. Furthermore, we propose a position estimation method using an estimation of the propagation velocity inside the human body. In addition, we show by computer simulation that the proposal method perform accurate positioning with a size of medical implanted devices such as a medicine capsule.*

**Keywords:** *medical implanted device, position estimation, ultra wideband, propagation velocity*

## . Introduction

Recently, wireless communication devices in the field of medical implant (cardiac pacemaker and capsule endoscope and so on) are studied extensively towards practical use. In the future, by transmitting vital data from one device to another implanted device in a network of medical implants, we can observe the body's condition and to detect any possible problem in the human body at anytime and anywhere. These can be a great help for doctors to diagnose and to cure diseases[4].

Considering that transmitted information of vital data is highly important and the need for long-lasting batteries, it is important that wireless communications of medical implanted devices to be highly-reliable with low transmission power consumption. In that regard, it is very important to know ranging and position of each device, because that can help to the optimization of the transmission power and to know the position of biological informations obtained from medical implanted device. In this pa-

per, we employ ultra wideband (UWB) systems as the transmission signals, because those achieve the requirements inside human body, high time resolution and low transmission power and to make a smaller device. Thus, we propose a method of position estimation of medical implanted devices inside the human body.

In free space, a type of position estimation algorithm is time-based technique[1]. Such a technique relies on measurements of travel time of signals between nodes. So, range and position can be known because the propagation velocity of microwaves in free space is constant. On the other hand, the human body is formed of various organs with complex structures. Furthermore, each organ has different characteristics of conductivity and relative permittivity. Because, propagation velocity inside human body is expressed as a function of the relative permittivity. For this reason, medical implanted devices placed in different positions cause different propagation velocities due to the EM waves travel through different tissues or organs. Furthermore, the received signal so distorted through the multipath channel caused by the refraction at the boundary of tissues inside human body[4]. As a result, position estimation errors may occur.

In this paper, we suppose the positioning of medical implanted devices in daily life that MRI and CT system don't exist around us. In this condition, a number of anchoring point is set beforehand and we estimate the position of medical implanted devices considering that the medical implanted devices move inside human body like the GPS system. On the premise that diagnostic images of inside human body can be obtained by magnetic resonance imaging (MRI) and computer tomography (CT) at the hospital. In analysis, we use the finite-difference time-domain (FDTD) method[3], which has been widely used to simulate the propagation of electromagnetic waves in biomedical tissues, considering the complex structure of the human body. We analyze the wave propagation inside the human body channel by FDTD method. At first, we calculate the propagation time based on the output of the correlator between the transmitter and the receiver. We apply an adaptive template synthesis method in multipath channel[2] for calculating the propagation time accurately. Furthermore, we estimate the propagation velocity inside human body. We divide the images into regions in order to estimate the relative permittivity of such regions. Then, we estimate the propagation velocity between implanted devices. Finally, we estimate the position of medical implanted devices with a time-based least squares (LS)

positioning approach[4].

This paper is organized as follows: In Section , some basic characteristics of dielectric materials which involve the human body tissue are described. The adaptive template synthesis method in multipath channel is described in Section . The proposed position estimation method is presented in Section . Simulation results are drawn in Section . Finally, conclusions are delineated in Section .

## . Radio Propagation in a Medium

A human body consists of various organs with complex structures. Furthermore, each organ has different characteristics of the electrical constants which are conductivity and permittivity.

We should consider the frequency band when we try to estimate the position of implanted devices using UWB radios. Indeed, the electromagnetic wave propagation in dispersive biological tissues is frequency dependent on permittivity and conductivity. The Cole-Cole model[4]. describes the frequency dependency of the complex permittivity. Figure 1 shows the relative permittivity and conductivity of muscle and fat.

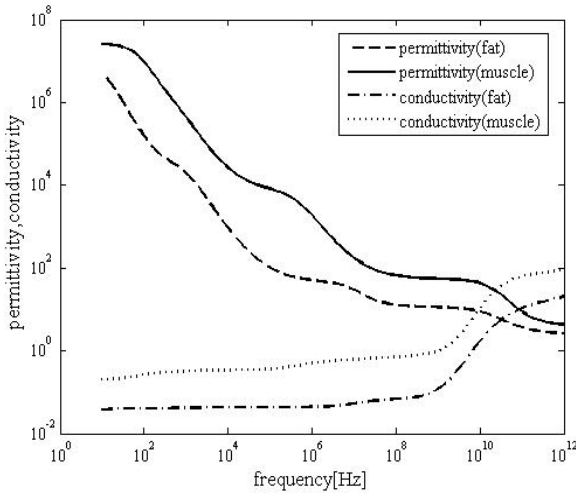


Figure 1- Dielectric parameters of muscle and fat

Furthermore, the propagation velocity of a homogeneous tissue is given by

$$v(\omega) = \frac{c}{\sqrt{\epsilon_r(\omega)}}, \quad (1)$$

where  $c$  is the velocity of light in the free space and  $\epsilon_r(\omega)$  is the relative permittivity of a human tissue. So propagation velocity has frequency dependency and differs by different body tissues. Because of this, a pulse broadening of a received UWB signal is caused by the group delay. Furthermore, the received signal so distorted through the multipath channel caused by the refraction at the boundary of tissues and the channel of frequency dependency inside human body.

## . Adaptive Template Synthesis Method

As mentioned above, the received signal so distorted and

pulse broadening through the human body channel. When we calculate the propagation time based on the output of the correlator between the transmitter and the receiver in Section , we need to use the template signal considering the received signal distorted and pulse broadening. If we use the template signal not considering the received signal distorted and pulse broadening, estimation errors of the propagation time increase. So we use the adaptive template synthesis method for UWB receiver to calculate the propagation time based on the output of the correlator accurately[2].

The template waveform is constructed as combination of orthogonalized elementary waveforms with certain coefficients. Generally, every UWB signal can be decomposed into some orthogonal elementary waveforms such as sine waves by Fourier series expansion independent of its kernel function. It is therefore possible to approximately construct a UWB template waveform by expanding the UWB signal into the weighted sum of several orthogonal elementary waveforms and truncating it to finite order. The synthesized template waveform is described as

$$w(t) = \sum_{k=1}^N C_k \int_{-\frac{T}{2}}^{\frac{T}{2}} L_k(t) \times W_{env}(t) dt, \quad (2)$$

where  $L_k(t)$  are the orthogonal elementary waveform and  $C_k$  are the corresponding coefficient.  $W_{env}(t)$  is the envelope which truncates each elementary waveform to finite duration. Rectangular window is used as  $W_{env}(t)$ , that is

$$W_{env}(t) = \begin{cases} 1 & (|t| \leq T/2) \\ 0 & (others) \end{cases}, \quad (3)$$

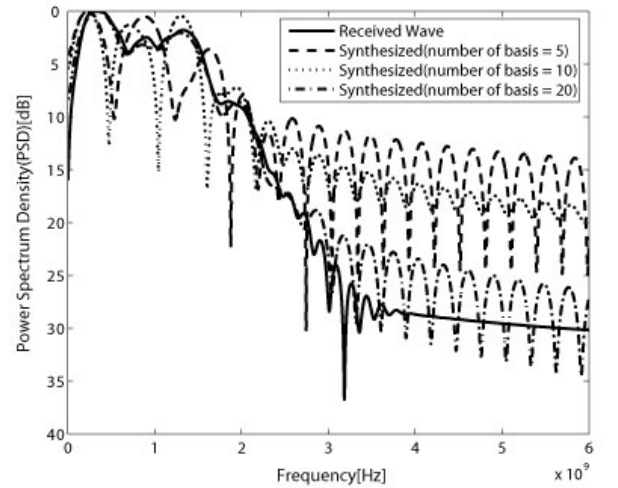


Figure 2- Spectrum of synthesized template waveform and one of the received wave inside human body

Generally, the coefficients  $C_k$  are derived as follows

$$C_k = \frac{2}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} r_s(t) L_k(t) dt, \quad (4)$$

where  $T$  is the pulse duration. If the set of orthogonal elementary waveform  $L_k(t)$  is complete, the synthesized template strictly matches to the ideal one. In reality, however, the number of coefficient and elementary waveforms should be finite.

In multipath channel such as the human body channel with very close range communication, we mainly consider Intra-pulse Interference (IPI) problem which is occurred when the multipath components are distributed more closely than typical pulse width. We use trigonometric function as orthogonal basis because it is closely-related to frequency domain and there is a possibility that we may analyze the human body channel in frequency domain. Figure 2 shows spectrum of synthesized template waveform and one of the received wave inside human body channel. It can be seen from Figure 2 that synthesized template waveform can well approximate the one of the received wave through the human body channel.

## . Proposed Method of Position Estimation

We proposed a position estimation method by estimating the propagation velocity inside of a human body. In addition to it, we calculate the propagation time from arbitrary tag points to node points (whose position is known) by using the estimated propagation velocity. Finally, we estimate the position of medical implanted devices using the LS approach.

The images of inside of the human body are acquired beforehand from a MRI or CT system. Our proposed method uses four medical implanted devices, whose locations are known, and we call them "node" in this paper. On the other hand, there is a medical implanted device, whose location is unknown, and we call it "tag" in this paper.

Our proposed method is composed of two stages. It is very difficult to estimate the real propagation velocity from all arbitrary tag points to node point directly. So, the real propagation velocity is estimated by the images of inside human body obtained from MRI or CT systems beforehand. So, we have large volumes of data of the real propagation velocity. Hence, we estimate the propagation velocity with two stages to simplify the estimation and to reduce the amount of data.

### - . First Stage

The procedure of the first stage is as follows. At first, we calculate the average relative permittivity of the region delimited by four nodes. The average relative permittivity  $\epsilon_{ave}$  and propagation velocity  $v_{ave}$  are calculated as

$$\epsilon_{ave} = \sum_{i=1}^I (\epsilon_{t(i)} p_{t(i)}), \quad (5)$$

$$v_{ave} = \frac{c}{\sqrt{\epsilon_{ave}}}, \quad (6)$$

Table 1 - The average relative permittivity of body tissues

Tissue	muscle	fat	blood	intestine
$\epsilon_r$	47.83	4.08	51.59	50.67
Tissue	lung	stomach	bone	tendon
$\epsilon_r$	42.56	56.99	17.09	37.61

where  $i$  is tissue number,  $I$  is total number of tissues,  $\epsilon_{t(i)}$  is the relative permittivity of a homogeneous tissue listed in Table 1[6], and  $p_{t(i)}$  is a percentage of the  $i$ th tissue.[5]

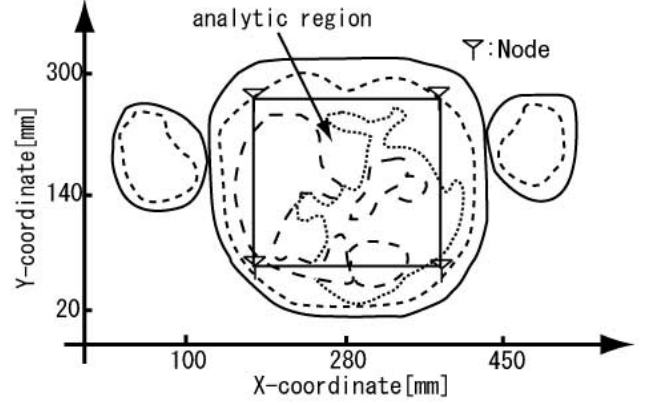


Figure 3- System model of the first stage

Secondly, we calculate the propagation time  $t_{n(x,y)}^1$  from four nodes to an arbitrary point in the studied region using  $v_{ave}$ . The propagation time in the first stage for the  $n$ th node  $t_{n(x,y)}^1$  is calculated as

$$t_{n(x,y)}^1 = \frac{d_{n(x,y)}}{v_{ave}}, \quad (7)$$

where  $x$  is x-coordinate of an arbitrary point,  $y$  is y-coordinate of an arbitrary point,  $d_{n(x,y)}$  is a direct length of a path from an arbitrary point to the four nodes, respectively. Also,  $x, y$  have 1 mm of separation.

Then, we estimate the travel times  $t_n$  of the received signal from the tag point to the four nodes by using a correlation receiver. In this approach, the desired estimation is given by the time shift of the template signal that yields the largest cross correlation with the received signal. Finally, we estimate the position of tag using the LS approach.

$$\theta(x, y)_1 = \min \sum_{n=1}^4 [t_n - t_{n(x,y)}^1]^2, \quad (8)$$

where  $\theta(x, y)_1$  is the estimate position of the first stage.

### - . Second Stage

In the stage, we use  $\theta(x, y)_1$  which is obtained from Equation (8). Firstly, we divide the images inside of the human body into several regions and estimate relative permittivity of a respective region. A relative permittivity of one region is calculated as

$$\epsilon_j = \sum_{i=1}^I (\epsilon_{t(i)} p_{t(i)}^j), \quad (9)$$

where  $j$  is a region number,  $i$  is a tissue number,  $\epsilon_j$  is an average relative permittivity of  $j$ th region,  $\epsilon_{t(i)}$  is the relative permittivity of a homogeneous tissue listed in Table 1, and  $p_{t(i)}^j$  is a percentage of the  $i$ th tissue in the  $j$ th region.

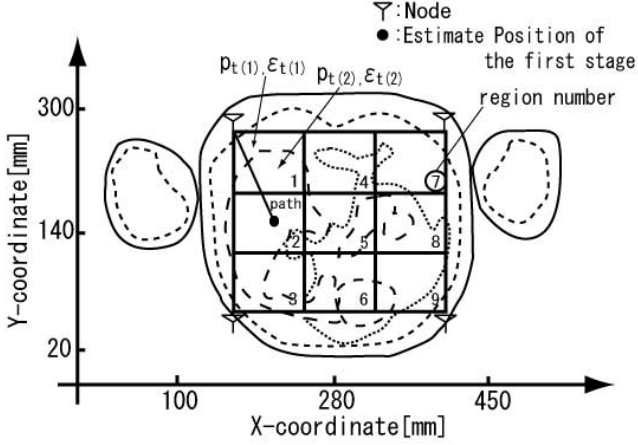


Figure 4- (3×3) regions system model of the second stage

Secondly, we estimate the relative permittivity  $\epsilon_n$  and propagation velocity  $v_n$  of the paths from four nodes to  $\theta(x, y)_1$ .

$$\epsilon_n = \frac{\sum_{k=1}^K (\epsilon_k d_k)}{d_{all}}, \quad (10)$$

$$v_n = \frac{c}{\sqrt{\epsilon_n}}, \quad (11)$$

where  $K$  is a number of regions through the propagation path from the  $n$ th node to  $\theta(x, y)_1$ ,  $d_k$  is a length of the path through the  $k$ th region, and  $d_{all}$  is a direct length of the path from  $n$ th node to  $\theta(x, y)_1$ . Then, we calculate the propagation time  $t_{n(x,y)}^2$  from four nodes to an arbitrary point using  $v_n$ . The propagation time  $t_{n(x,y)}^2$  is calculated as

$$t_{n(x,y)}^2 = \frac{d_{n(x,y)}}{v_n}, \quad (12)$$

where  $x$  is x-coordinate of an arbitrary point,  $y$  is y-coordinate of an arbitrary point, and  $d_{n(x,y)}$  is a length of a path from an arbitrary point to four nodes, respectively.

And  $x, y$  have 1 mm of separation.

Finally, we estimate the position of tag using the LS approach.

$$\theta(x, y)_2 = \min \sum_{n=1}^4 [t_n - t_{n(x,y)}^2]^2, \quad (13)$$

where  $t_n$  is the travel time of the received signal from tag to the four nodes, and  $\theta(x, y)_2$  is the estimate position of the second stage.

## . Numerical Simulation

This section presents simulations to demonstrate the performance of the proposed method.

### . Simulation Model

The images of MRI or CT system are two-dimensional images. In this paper, we consider only two dimensional images. Figure 5 and Figure 6 show the simulation image obtained by

the FDTD of Remcom Co., Ltd. Figure 5 is the image of a cross-section of a human body at high 137.5 cm and Figure 6 is that of a human body at high 157.5 cm. These model contain human body tissues such as muscle, fat, blood, bone, stomach, intestine, bladder, tendon, lung. The following is the characteristic of these models.

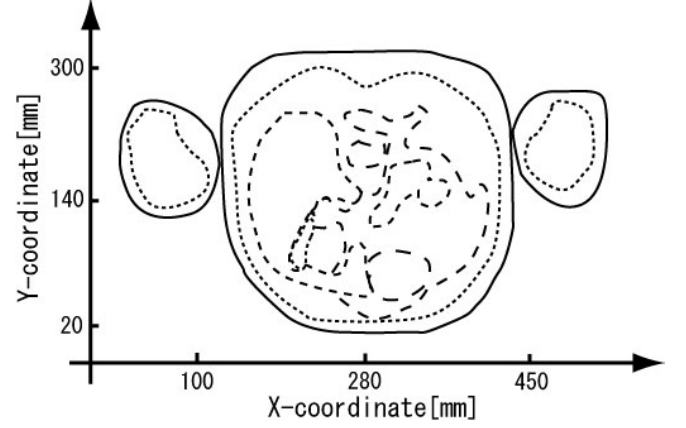


Figure 5- Simplified 2D human body model of 137.5 cm high

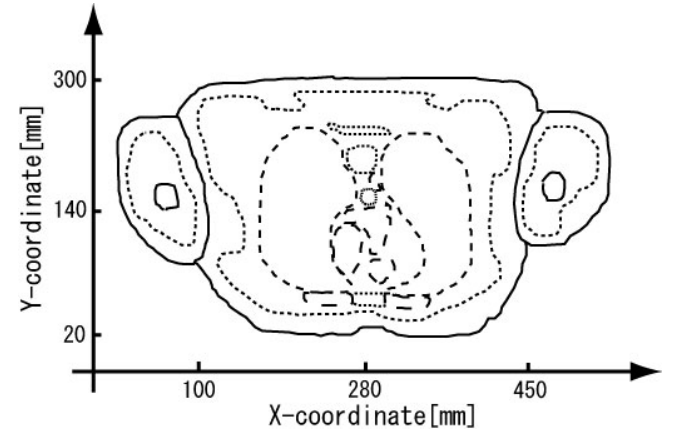


Figure 6- Simplified 2D human body model of 157.5 cm high

As mentioned before, we consider four nodes at positions (171,61), (400,61), (171,240), and (400,240). On the other hand, there is one tag device.

### . Performance Evaluation of Proposed Method

We evaluate the performance of our proposed method. In this paper, we consider the human body channel as the static model. At the second stage, we divide the large region inside of the four nodes into some smaller regions. The number of partitions is from (3×3) to (7×7) for x-direction and y-direction. We compare the proposal with the method using the average relative permittivity obtained in Table 1, in order to estimate the propagation velocity from all arbitrary tag points to a node point. The average relative permittivity inside the human body is assumed to be 2/3 of muscle and 1/3 of fat. The proportion of the tissue of high water content (HWC) to the low water content (LWC) is 2:1 in a human body, where the typical tissue of HWC is muscle and fat for LWC. Simula-

tion specifications are listed in Table 2.

Table 2 – Simulation Specification

Analysis Model	Body model of FDTD
Transmit Waveform	Gaussian Mono Pulse
Used Band Frequency	0 ~ 4.0 [GHz]
Time Step	1.926 [ps]
Sequence	MLS (length=7)
Pulse Interval	5000 [time step]
Kind of Noise	AWGN

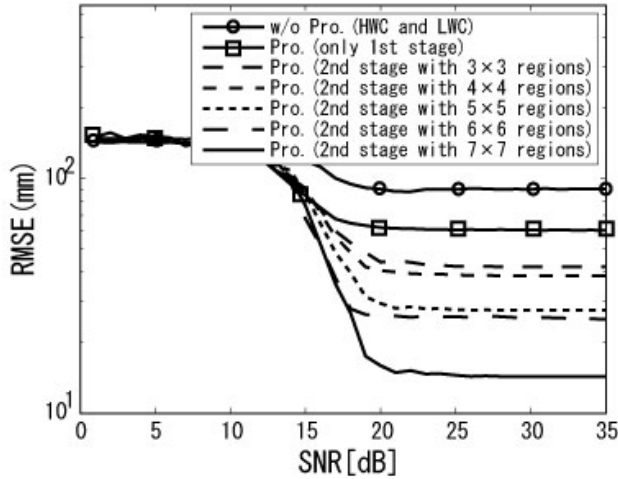


Figure 7- Comparison of positioning error of 137.5 cm high

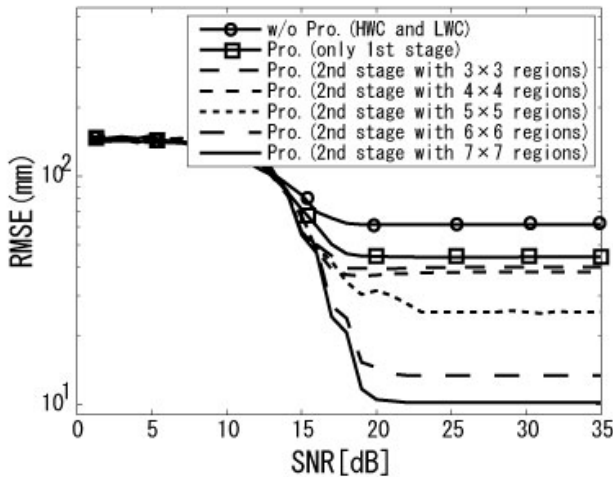


Figure 8- Comparison of positioning error of 157.5 cm high

Figure 7 and 8 show the result of position estimation. The horizontal axis shows SNR and the vertical axis shows RMSE of position estimation. Simulation results show that accuracy of proposed method of positioning is around the size of medical implanted device such as a capsule endoscopes. In addition, simulation results show that when the regions are smaller, the positioning accuracy is better.

## . Conclusion

In this paper, we analyze the propagation of UWB signals inside of human body tissues with the FDTD method. Especially, we focused on the time-based position estimation of medical implanted devices inside human body. Firstly, we apply an adaptive template synthesis method in multipath channel for calculate the propagation time accurately based on the output of the correlator between the transmitter and the receiver.

Moreover, we have proposed the position estimation method of medical implanted devices using estimation of the propagation velocity inside of the human body. Simulation results show that the proposed method gives a positioning accuracy around the size of medical implanted devices such as capsule endoscopes. In addition, simulation results show that if the regions are smaller, the positioning accuracy is better.

In the future, we estimate the propagation velocity inside human body without prior information of human body images. Furthermore, we expand our 2D model inside human body to 3D model. In 3D model analysis, we additionally need to consider the more complex structure of human body tissues. So the signals refract at the boundary of tissues many times. So we need to estimate so precisely the increase of propagation time based on the refractions of the signal.

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