人体通信的建模、仿真和实现

The Modeling Simulation and Implementation of Intra-Body Communication 英语

宋勇 郝群 著

北京理工大学出版社

图书在版编目（CIP）数据

人体通信的建模、仿真和实现 = The Modeling，Simulation and Implementation of Intra-Body Communication：英语/宋勇，郝群著. —北京：北京理工大学出版社，2016.1

ISBN 978-7-5682-1725-5

Ⅰ. ①人… Ⅱ. ①宋… ②郝… Ⅲ. ①人体-通信技术-建模系统-英语 ②人体-通信技术-仿真系统-英语 Ⅳ. ①TN91

中国版本图书馆 CIP 数据核字（2015）第 315507 号

出版发行 / 北京理工大学出版社有限责任公司
社　　址 / 北京市海淀区中关村南大街 5 号
邮　　编 / 100081
电　　话 /（010）68914775（总编室）
　　　　　（010）82562903（教材售后服务热线）
　　　　　（010）68948351（其他图书服务热线）
网　　址 / http://www.bitpress.com.cn
经　　销 / 全国各地新华书店
印　　刷 / 保定市中画美凯印刷有限公司
开　　本 / 787 毫米×1092 毫米 1/16
印　　张 / 8
字　　数 / 128 千字
版　　次 / 2016 年 1 月第 1 版 2016 年 1 月第 1 次印刷
定　　价 / 42.00 元

责任编辑 / 梁铜华
文案编辑 / 梁铜华
责任校对 / 周瑞红
责任印制 / 王美丽

Yong Song

received his Ph. D. degree from the Department of Opto-electronic, Beijing Institute of Technology, China, in 2004. In 2007, he was an associate professor with the School of Information Science and Technology, Beijing Institute of Technology. From 2009 to 2010, he was a visiting scientist with the Institute of Optics, University of Rochester, Rochester, NY, America. Recently, he is a professor and the director of the Institute of Opto-Electronic Instrument, Department of Opto-electronic, Beijing Institute of Technology. Dr. Song was selected into the Excellent Talents of Beijing in 2011, and awarded the Excellent Young Scholars Research Fund of Beijing Institute of Technology in 2012. Dr. Song's research with respect to Intra-Body Communication began in 2006, which was supported by the National Natural Science Foundation of China, the Excellent Talent Cultivation Plan of Beijing, and the Basic Research Foundation of Beijing Institute of Technology. He holds the first patent of Intra-Body Communication of China, and has published over 40 technical articles in this field.

Qun Hao

received her Ph. D. degree from the Department of Precision Instruments and Mechanology, Tsinghua University, China, in 1997. In the same year, she joined the faculty of the Department of Opto-electronic Engineering in Beijing Institute of Technology. She became a full professor in 2003. She was a guest researcher at University of Tokyo, Japan, during 1999 – 2001, and a visiting professor at the Department of Biomedical Engineering, Case Western Reserve University, USA in 2011. She is vice chairman of Key Laboratory of Ministry of Education of Bionic Robot and System, director of China Instrument and Control Society and director of Chinese Society for Measurement. She was selected into Trans-Century Training Programme for Talents by the State Education Commission in 2003. Her research interests include optics and precision measurement and opto-electronic sensor technology.

Acknowledgements

Firstly, I would like to dedicate my most sincere gratitude to professor Jannick Rolland of University of Rochester, NY, America. Without her selfless practical support, enthusiasm, patience, and flexibility in managing the tight publishing schedule, this book would never have become reality. Moreover, I would like to show appreciation to professor Xingde Li of the Department of Biomedical Engineering, Johns Hopkins University, America, who provided much good advice for this book with professional research.

I would express my heartfelt thanks to research fellow Chengxin Pei of PLA Chemical Defense Research Institute, research fellow Hongbo Jia of Aviation Medicine Research Institute, and professor Dongsheng Wang of Tsinghua University, China, for their devotions throughout the preparation of this book. Especially, I would like to show appreciation to professor Fengmei Cao, the vice director of Educational Administration Department of Beijing Institute of Technology, who provided essential support for the publishing of this book. My special thanks belong to editor Dingyi Li of Beijing Institute of Technology Press, who provided a lot of editorial support for this book.

I would also like to express my gratitude to the editorial staff of Beijing Institute of Technology Press, the publisher of this book. In particular, I am grateful to research fellow Xiaochen Bai of Academy of Military Medical Sciences, Professor Lin Li of Beijing Institute of Technology among these crowds who helped me with the editorial matters. Additionally, I appreciate my students, who are the doctoral student of Kai Zhang; the master students of Maoyuan Li, Xianyue Kong, Shiyu

Zhang, Wansong Li, Dingchao Xie, Jingwen Wang, Bangzhi Kang and Guang Yang, Yun Li; the undergraduate students of Ruobing Huang, etc. , for their diligent work to review the book.

This work would never come true without the financial support from the following funding organizations: Ministry of Industry and Information Technology, National Natural Science Foundation of China (NSFC), Excellent Talent Cultivation Plan of Beijing, and Beijing Institute of Technology. I couldn't have access to the development in this promising field without their generous support.

Yong Song
July 16, 2015

CONTENTS

1. Introduction

1.1 Concept of Intra-Body Communication

Intra-Body Communication (IBC) is a signal transmission technology using the human body as transmission medium for electrical signals. IBC was firstly proposed by Zimmerman[1]. In an IBC system shown in Fig. 1.1, signals from the IBC transmitter are coupled into the human body through the transmitting electrode, and signal transmitting within the human body is detected by the IBC receiver through the receiving electrode. Finally, signal transmission within the human body can be achieved.

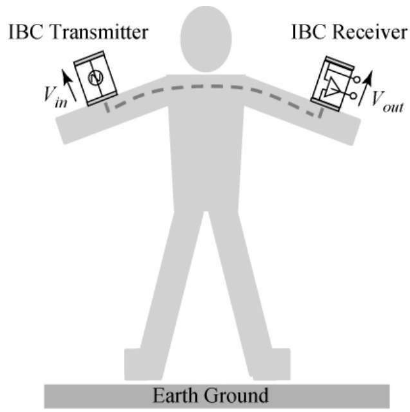

Fig. 1.1 The concept of Intra-Body Communication

IBC technology is based on the near-field coupling mechanism, in which signals are confined in the human body, which acts as a signal guide that couples signals electrostatically. As a result, low-frequency bands without large antennas can be used and there is no need to transmit high-power signals, thus both the power consumption and the interference from the outside environment can be considerably reduced. On the other hand, since the signal frequency used in IBC is lower than the resonant frequency of the human body (approx. 70 – 100 MHz), it does not resonate with the human body[2]. Namely, the human body cannot be considered as an antenna. Therefore, signals mainly propagate along the surface of the human body, rather than radiating into the surroundings[8,17]. Additionally, clothing and sole can be considered as a capacitance in an IBC system, and thereby it can couple Alternating Current (AC) signals. As a result, Intra-Body Communication can also be achieved in case that there is clothing or sole and the other mediums between IBC transceiver and the human body.

1.2 Safety Issue

Since the human body is considered as signal transmission medium in an IBC system, safety is an important issue for IBC. As for the limitation of electric field to the human body, the international guidelines have been issued by the Commission on Non-Ionizing Radiation Protection (ICNIRP)[3] and IEEE Standard for Safety Levels[4]. Table 1.1 shows the limitation represented as threshold current to the human body. Actually, the contact currents of Intra-Body Communication are far lower than the threshold current corresponding to the different frequency ranges shown in Table 1.1. Moreover, the primary sensation of the human body corresponding to the frequency range of 100 kHz – 10 MHz is heat. Generally, if the increase of the temperature is less than 1 degree, it will not result in adverse heating effect[5]. Therefore, the safety of IBC can be guaranteed.

Table 1.1 The limitation of threshold current to the human body[3]

Indirect effect	Threshold current/mA			
	50/60 Hz	1 kHz	100 kHz	1MHz
Touch perception	0.2 – 0.4	0.4 – 0.8	25 – 40	24 – 40
Pain on finger contact	0.9 – 1.8	1.6 – 3.3	33 – 55	28 – 50
Painful shock	8 – 16	12 – 24	112 – 224	n/a
Severe shock difficulty	12 – 23	21 – 41	160 – 320	n/a

1.3 Advantages of IBC

Compared with the short distance wireless communication technologies, such as Bluetooth and Zigbee, Intra-Body Communication technology has several advantages, which can be described as follows:

(1) High communication quality. Since signals mainly transmit within the human body and little radiation leaks out in Intra-Body Communication, IBC avoids the disturbance of environment electromagnetic noise. Therefore, compared with conventional short distance wireless communication technologies, it has comparatively better communication quality.

(2) Low energy consumption. As a special cable communication using the human body as transmission medium, signal transmission based on the human body requires comparatively lower energy consumption[6]. Therefore, low power consumption is an important characteristic

of IBC technology.

(3) Interaction based on body motion[7]. In an IBC system, signal transmission path can be established by the motions of the human body[8], such as grasping, sitting down, walking or standing. Therefore, the interactions such as starting a device, collecting data and triggering a service can be achieved by the natural motions of the human body, which is very useful for the interaction among wearable devices and electronic devices embedded in environment.

Given the advantages mentioned above, it is believed that Intra-Body Communication technology will offer significant advantages in many fields, such as Personal Area Network (PAN), biomedical monitoring[9,10], interaction between human and environment[11,12] and other related fields.

1.4 Applications of IBC

The applications of IBC technology can be divided into biomedical monitoring, consumer electronics, security system and so on.

1.4.1 Biomedical monitoring

Recently, with the requirements of the remote biomedical monitoring, more and more attention has been paid to the personal health systems[13] based on Body Sensor Network (BSN). In these systems, a patient may have a set of biomedical sensors attached to or implanted into the body, which are used for measuring physiological signals, such as electrocardiogram (ECG), electromyography (EMG), blood pressure and pulse oximetry, etc. Meanwhile, the communication technologies used in this field should meet the requirements listed as follows.

(1) Low power consumption. Generally, since the communication device used in this field should work for a long time with a small battery, its power consumption should be decreased as low as possible.

(2) High safety. The signal transmission process should not interfere with the biomedical activities of the human body, while the existing safe regulations must be strictly satisfied.

(3) High communication quality. The communication quality should not be influenced by the outside electromagnetic environment, which becomes more and more complex with the greatly increase of wireless communication devices.

In some personal health systems, sensors communicate by wire, which is not convenient for patients and is hard to achieve real-time biomedical monitoring. Meanwhile, the conventional wireless communication technologies, such as Wireless Local Area Networks (WLAN) and Bluetooth and Zigbee, have been used in BSN field. Table 1.2[5] compares WLAN, Bluetooth and Zigbee. However, the above conventional technologies cannot meet the requirements of BSN completely. For instance, WLAN and Bluetooth modules have comparatively higher power consumption, which is a considerable problem for the battery-powered sensors. Meanwhile, Zigbee model generally offers insufficient data transmission rates for the biomedical monitoring. Therefore, new communication technology is needed for meeting the requirements of biomedical monitoring.

Table 1.2 Comparison of the short distance wireless technologies for BSN

Technology	Frequency	Data rate	Power	Size
WLAN	2.4/5.1 GHz	54 Mbit/s	100 mW	PC card
Bluetooth	2.4 GHz	723.1 kbit/s	10 mW	PCB module
Zigbee	868 MHz	20 kbit/s	1 mW	PCB module

As a novel signal transmission technology, Intra-Body Communication technology has the characteristics of high communication quality, low power consumption and interaction based on body motion, etc. It will play an important role in the biomedical monitoring. In the biomedical monitoring system based on IBC technology, as shown in Fig. 1.2[14], all the wearable sensors as well as implanted sensors can communicate using the human body, and thereby establish a biomedical monitoring system. Meanwhile, a central link sensor can be integrated in a wrist watch or the other portable device (such as cell phone), which collects all the biomedical data of the human body and communicates with hospital via conventional high bandwidth wireless technology. Finally, the biomedical data of the patient is available for his/her doctor, and thereby the patient's health can be monitored almost anywhere and anytime.

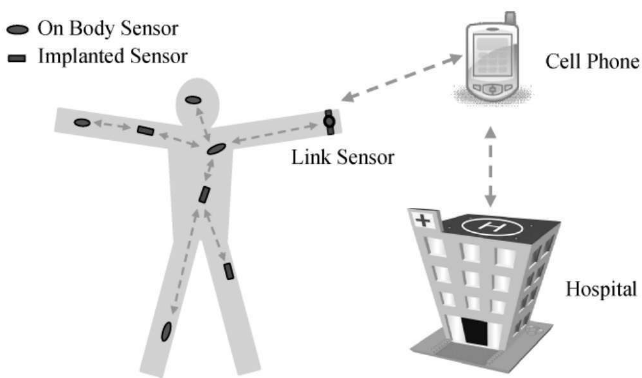

Fig. 1.2 The biomedical monitoring based on IBC technology

1.4.2 Consumer electronics

One of the most important characteristics of IBC technology is that the interaction among wearable devices and electronic devices embedded in environment can be achieved by the natural motions of the human body, which will help to achieve ubiquitous computing. Moreover, besides the human body, water and metals also have good conductivity, which indicates that IBC technology can also be suitable for these materials. Therefore, the application of IBC technology can be extended from the human body to its surroundings.

1.4.2.1 Interaction among the wearable devices

In consumer electronics field, the wearable devices can communicate with each other, and the interaction among wearable devices can be achieved by using Intra-Body Communication technology. For instance, recently, many wearable devices such as electronic watch have to be integrated with Central Processing Unit (CPU), memory and display. If these devices can establish a network using IBC technology, all the resources of BSN can be shared by the wearable devices[1], and thereby we may only need a CPU, a memory and a display for the whole BSN in the future.

1.4.2.2 Interaction among the wearable devices of the different human bodys

As a signal transmission technology using the human body as signal transmission medium, IBC technology makes it possible to interact with each other among the wearable devices of the different human bodys. As a result, two individuals can exchange data (such as electronic business cards) by shaking hands[15], as shown in Fig. 1. 3.

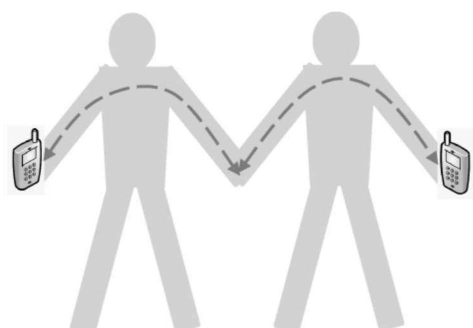

Fig. 1. 3 Two individuals exchanging electronic business cards by shaking hands

1.4.2.3 Interaction Between wearable devices and environment

Using IBC technology, wearable devices can communicate with the electronic devices embedded in the environment by the physical contact between the human body and the electronic devices. For instance, when a person touches a door knob, the electronic devices embedded in the door knob can verify the authentication information stored in the wearable devices using IBC technology, and then the door will be opened automatically. Therefore, the interaction is implemented by the natural motion (turning knob) of the human body. Furthermore, the other novel applications of IBC technology can also be found, such as getting the detailed information of an exhibit by touching the electronic devices embedded in environment[15], as shown in Fig. 1.4, etc.

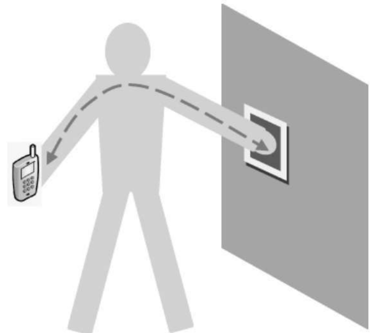

Fig. 1.4 Getting the detailed information of an exhibit by touching the electronic devices embedded in environment

1.4.2.4 Interaction electronic devices through conductive material

Since IBC technology is also suitable for the materials with good conductivity (such as water, metal), electronic devices based on IBC technology can automatically communicate with each other when a person connects conductive materials. For instance, using IBC technology, notebook computers belonging to different persons can be connected with each other and established into a conference system automatically when they are put on a conductive metal sheet.

1.4.3 Secure space

A secure space system based on Intra-Body Communication technology has been proposed[16]. In the proposed system, an IBC transmitter is integrated into an Identity (ID) card, which is put in a pocket. When a person with the authorized ID card stands on the floor in front of the door, the authorized information transmits from the ID card to the IBC receiver embedded in the floor along the person's body path. Finally, the IBC receiver verifies the authorized information, and the door is automatically opened. As a result, the authentication certificate process is implemented by the natural motion (standing) of the human body. Moreover, IBC technology is also used for dividing different zones with different security levels in the secure space system[16]. A security lamp will flash in case that an unauthorized person walks into the zone. Using the IBC technology mentioned above, the inconvenience brought by the complex authentication certificate is avoided, and a "secure office space" can be achieved.

1.4.4 Application prospect

As a novel signal transmission technology, Intra-Body Communication technology has the characteristics of good communication quality, low power consumption, human-computer interactions based on body motions, and thereby it will offer significant advantages in medical information systems, payment systems and smart spaces, etc. Some promising applications in the future can be described as follows.

- Using the medical information system based on IBC technology, doctors may gather the biomedical information of their patients just by touching the patients' wrists.
- The payment of subway tickets can be implemented synchronously when passengers walk through the gate integrated IBC devices.
- Using IBC devices integrated in automobiles and aircraft, the individual habits of drivers and passengers (such as seat height, backrest angle) can be recorded. Therefore, the systems can automatically adjust to their favorite settings next time.

Finally, it should be noted that Intra-Body Communication is very helpful to achieve ubiquitous computing in the future. Nowadays, massive information has reached our computer, mobile phone and the Internet interface embedded in the wall, but how can the information be enrolled into our life conveniently and naturally? Actually, Intra-Body Communication provides a good choice, which helps us to get information from different terminals by our natural body motions, such as touching, sitting, holding and stepping.

1.5 The Scope of This Book

1.5.1 The modeling and the simulation of IBC

To guarantees the safety of the human body, the modeling and the simulation serve as an important role in the investigation of Intra-Body Communication. Two methods have been used in this field. One is the transfer function method[17,18], in which the transfer function of IBC is developed firstly for describing the mathematical relations of the different parts in IBC system, and then the IBC simulation can be achieved by using the transfer functions. The other method can be called the Finite-Element method[19], in which the Finite-Element (FE) model of the human body parts is developed firstly, and then the IBC simulation is implemented by using the developed FE model.

1.5.2 The implementing methods of IBC

Generally, an IBC system consists of a transmitter, a sensor and the corresponding receiving circuit, in which the transmitter is used for modulating and coupling the base band signals into the human body through the transmitting electrode, the sensor is used for detecting the signal transmitting within the human body at the receiver terminal, while the receiving circuit is mainly used for processing (such as amplifying, filtering and demodulating) the signals received by the sensor. On the other hand, in order to achieve reliable signal transmission based on the human body, the sensor plays an important role in IBC system. Recently, some sensors used for IBC have been developed, which can be devided into electrical sensors and Electro-Optical (EO) sensors. However, since the electrical sensor has comparatively lower input impedance and is easy to be interfered by electromagnetic noise, the typical signal transmission distance based on this kind of sensor is only approximate 30cm and the corresponding signal transmission rate is limited to 40 kbps[8]. As for the Electro-Optical sensor, the influence of electrical noise can be greatly decreased because of its extremely high input impedance. Moreover, the ground electrode of the EO sensor is electrically isolated from the electronic circuits, which eliminates the influence of the floating ground potential[20]. As a result, both the noise and the distortion of the receiving signal are decreased greatly, and thereby it results in comparatively higher signal transmission rate. Therefore, the EO sensor is believed as a suitable sensor for detecting signal transmitting within the human body.

1.5.3 Book contents

The modeling, the simulation and the implementation of Intra-Body Communication as well as the authors' works in these fields are introduced in this book. The contents of this book can be described as follows:

In Chapter 2, the theory foundations of Intra-Body Communication have been discussed. We address the types of Intra-Body Communication, then the theoretical explanation of galvanic coupling IBC and electrostatic coupling IBC have been discussed in detail.

In Chapter 3, the transfer functions of IBC system are introduced by the modeling of the galvanic coupling IBC as well as electrostatic coupling IBC, while both the *in-vivo* measurements and the corresponding mathematical simulations based on the proposed transfer function are carried out along with different signal transmission paths of the human body. The experiment results show that the signal attenuations of simulation results coincide with the corresponding *in-vivo* measurement results.

A Finite-Element method for modeling the whole human body is introduced in Chapter 4, while both the simulations of the IBC based on the whole human body and the corresponding *in-vivo* measurements have been carried out. Finally, some important conclusions have been deduced.

In Chapter 5, the implementing methods of IBC based on Mach-Zehnder EO modulator