	ハク エムディ　イスマイル
氏　　名	**HAQUE Md Ismail**
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学位論文題目	Study on Wireless Transmission from In-body to On-body and On-body to Off-body for Healthcare Purpose in an Aging Society （高齢化社会におけるヘルスケアを目的としたインボディからオンボディ／オンボディからオフボディへの無線伝送に関する研究）
論文審査委員	主査　教授　王　建青 教授　菊間　信良 教授　平田　晃正 准教授　齊藤　一幸（千葉大学） 教授　Georg Fischer (FAU)

論文内容の要旨

As the aging society problem draws great attention, the sensing technology and monitoring scheme of bio-signals has advanced tremendously over the years. The bio-signals include electromyogram, electrocardiogram, electroencephalogram, electrooculogram and many others. They are widely employed in medical and healthcare applications. For example, the body area network (BAN) with wearable sensing technologies can collect these signals as vital data for health-state monitoring, which is considered as an emerging solution to soaring healthcare costs and shortages of medical resources. In addition to medical treatment and healthcare, they could also be considered as an irreplaceable interface between human body and devices. In this study, a core idea runs through all works: In-body to On-body technology, On-body to Off-body technology to prevent the vulnerabilities of aged people or patient and combination of energy harvesting technique to operate this technology independently. Contents of the thesis is as follows:

In Chapter 2, we discussed the necessity of channel modeling as a vital step in designing transceivers for wireless in-body to on-body communication systems due to

the extremely challenging environment of the human body. The in-to-on body path loss and group delay were first analyzed using an electric dipole and a current loop in the 10-60 MHz human body communication band. A path loss model was derived using finite difference time domain (FDTD) simulation and an anatomical human body model. As a result, it was found that the path loss increases with distance in an exponent of 5.6 for dipole and 3.9 for loop, and the group delay variation is within 1 ns for both dipole and loop. Moreover, the electric and magnetic field distributions revealed that the magnetic field components dominate in-body signal transmission in this frequency band. Based on the analysis results of the implant channel, the link budget was analyzed. An experiment on a prototype transceiver was also performed to validate the path loss model and bit error rate (BER) performance. The experimentally derived path loss exponent was between the electric dipole path loss exponent and the current loop path loss exponent, and the BER measurement showed the feasibility of 20 Mbps implant communication up to a body depth of at least 15 cm.

In Chapter 3, a novel monitoring system was discussed using Bluetooth low energy (BLE) beacon to detect wanderer location identification. BLE beacons can be mounted in shoes for convenience, and a shoe-mounted directional antenna is expected to efficiently radiate the beacon signals to the data server of the monitoring system. A directional array antenna with planar or curved structure was designed on the shoe surface for this purpose. The antenna was designed to sweep diagonally upward from 10° to 50°, and the simulated and measured S11 performances revealed reasonable agreement. The antenna was assumed to be used in an urban environment, and a directional patch array antenna with dielectric lens was also designed to receive beacon signals by mounting it on utility poles. According to a feasibility experiment result of elderly wanderer position identification, the designed directional antenna can provide an almost 100% position identification rate if a wanderer is within 20 m from a smart phone user or a utility pole.

In Chapter 4, we proposed the aspects of piezoelectric materials as energy harvester system for powering our designed shoe-mounted beacon. We provided a state-of-the-art of pressure produced voltage about energy harvesting system, which use NKN and BCTZ piezo materials. Implementation of our approach was conducted by placing the piezo materials of shoe sole. Experiments were performed to verify its effectiveness. The maximum produced AC voltage from one piezo sheet was found to be around 2.3 V as shown in time domain waveform. Furthermore, we highlighted the advantages of using a full-wave passive rectifier over the conventional full-wave bridge rectifier for AC-DC conversion. Together with multiple piezo sheets and passive rectifier, a desirable output power may be accomplished to operate BLE mounted beacons.

Chapter 5 is a summary of the thesis.

論文審査結果の要旨

As the aging society problem draws great attention, the sensing technology and monitoring scheme of bio-signals has advanced tremendously over the years. The bio-signals include electromyogram, electrocardiogram, electroencephalogram, electrooculogram and many others. They are widely employed in medical and healthcare applications. For example, the body area network (BAN) with wearable sensing technologies can collect these signals as vital data for health-state monitoring, which is considered as an emerging solution to soaring healthcare costs and shortages of medical resources. In addition to medical treatment and healthcare, they could also be considered as an irreplaceable interface between human body and devices. In this study, a core idea runs through all works: In-body to On-body technology, On-body to Off-body technology to prevent the vulnerabilities of aged people or patient and combination of energy harvesting technique to operate this technology independently.

Firstly, the applicant investigated the channel modeling as a vital step in designing transceivers for wireless in-body to on-body communication systems due to the extremely challenging environment of the human body. The in-to-on body path loss and group delay were first analyzed using an electric dipole and a current loop in the 10-60 MHz human body communication band. A path loss model was derived using finite difference time domain simulation and an anatomical human body model. As a result, it was found that the path loss increases with distance in an exponent of 5.6 for dipole and 3.9 for loop, and the group delay variation is within 1 ns for both dipole and loop. Moreover, the electric and magnetic field distributions revealed that the magnetic field components dominate in-body signal transmission in this frequency band. Based on the above analysis results, the link budget was analyzed. An experiment on a prototype transceiver was also performed to validate the path loss model and bit error rate performance. The experiment showed the feasibility of 20 Mbps implant communication up to a body depth of at least 15 cm.

Secondly, the applicant developed a shoe-mounted directional antenna for a monitoring system using Bluetooth low energy (BLE) beacon to detect wanderer location identification. The directional array antenna with planar or curved structure was designed on the shoe surface. The antenna was designed to sweep diagonally upward from 10° to 50°, and the simulated and measured S11 performances revealed reasonable agreement. The antenna was assumed to be used in an urban environment, and a directional patch array antenna with dielectric lens was also designed to receive BLE beacon signals by mounting it on utility poles. According to a feasibility experiment result of elderly wanderer position identification, the designed directional antenna can provide an almost 100% position identification rate if the wanderer is within 20 m from a smart phone user or a utility pole.

Finally, the applicant investigated the possibility to use piezoelectric materials as energy harvester to power a BLE beacon mounted on shoes. Implementation of this approach was conducted by placing the piezo materials of shoe sole. Experiments were performed to verify its effectiveness. The maximum produced AC voltage from one piezo sheet was found to be around 2.3 V as shown in time domain waveform. Furthermore, the applicant demonstrated a full-wave passive rectifier for AC-DC conversion. Together with multiple piezo sheets and passive rectifier, a desirable DC output voltage can be expected to operate a BLE beacon mounted on shoes.

In conclusion, the content of this thesis has been published as two journal papers. So, it is worth the award of a Doctor of Engineering degree.