Low Energy On-Body Communication for BSN

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Abstract—**Low power on-body communication is introduced. The human body surface is examined for the communication channel and 10KHz-100MHz frequency band, 'bodywire', is found to be effective in the wireless on-body communication. DCI is proposed to avoid any intentional ground electrode for the capacitive coupling. A CMOS transceiver chip for the on-body communication is fabricated and can achieve 2Mbps with 0.2mW power consumption. The architecture of the BSN controller is proposed and fabricated with CMOS. It has a 16b RISC and a schedule director with TCAM. It can separately control 254 sensor nodes and consumes 14uW in normal mode and 160uW in alert mode including leakage current. The fabricated chip is used to transmit MP3 data from the finger tip to the earphone to enjoy the music. In addition, the BSN controller can detect the emotion of the user by using the data from the sensor nodes transmitted through on-body communication channel.**

Keywords— **On-Body Communication, BSN transceiver, BSN controller, Low Power, High Speed.**

I. INTRODUCTION

Body sensor network opens up many new potential applications in the medical, healthcare and entertainment areas[1]. Although many researches have been directed to the in/through-body wireless communication or off-body wireless communication of Fig 1 very seldom research on the wireless on-body communication has been reported for BSN application[2]. The off-body, BSN has used the frequency band of 2.4GHz for its compatibility with the existing wireless communication standards such as Bluetooth or UWB[3]. It can transmit the signal to the relatively long distance, ~10m. But, its energy consumption for the communication is relatively high, the order of 10nJ/bit. The <50Cm distance in-body communication system supports low speed data rate, ~100bps, with 430MHz carrier frequency. The short distance, <5Cm, through-body communication between implanted device and external read-out terminal can support Mbps data rate using inductive coupling of 415MHz carrier. But its available power is less than milliwatts due to biological safety levels of 10mW/Cm^2 and again it gives a limitation in the channel capacity.

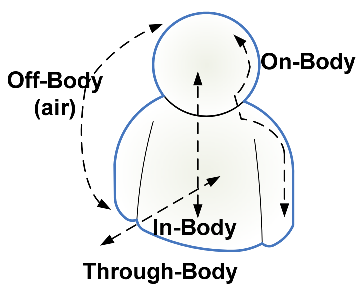

Fig. 1 Types of Body Channel Communication

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In this paper, the on-body communication with less than 200MHz frequency band is introduced for low energy and high speed body sensor network. The proposed on-body communication covers < 2m distance on the skin of the human body. Its usage is relatively safe and convenient compared to other communication methods. For the frequency range ~ 2.4GHz, most of the signal energy is outside of the human body due to the radiation and skin effect[3]. Therefore, the signal is not transmitted on the body or in the body. The proposed on-body communication uses 10KHz – 200MHz band. Early researches of the on-body communication studied <1MHz frequency band but its signal loss is too large to get the practical application and its signal transfer rate is relatively low[4,5,6]. Compared with other body communication band, the frequency band of our on-body communication has been relatively less studied.

We examine the channel characteristics of the human body. Based on the results of the study, the high speed low power transceiver and intelligent controller ICs are designed and fabricated. Their details will be explained in the following sections. In addition, the applications of the on-body communication to the BSN will be introduced.

II. MODEL OF THE BODY CHANNEL

The blood has the lowest resistivity, 1.5 Ωm, in the human body and transmits most of the signal. The average conductivity of the human body is in the range of 0.1 – 0.5 S/m for the frequency band of 100KHz – 300MHz.

The Fig. 2 shows the schematic diagram of the body channel communication. The external signal is capacitively coupled to the conducting material below the skin. Then, the receiver recovers the signal by capacitive coupling at a distant location.

The coupling capacitor can be quasi statically calculated and the human body is assumed as an ideal conductor, a point node[4]. However, as the frequency increases, the effect of the coupling capacitor decreases and the impedance of the human body cannot be ignored. A distributed RC model of Fig. 3 is proposed to describe the signal transmission through the human body for the 1MHz-300MHz band.

The unit RC circuit is obtained when the body is segmented into 10Cm length as an unit block, and the circuit model of the human body can be constructed by the string of the unit blocks. The resistance of the unit block in this study is 15Ω and its coupling capacitance to the earth ground is 8pF[7]. The air coupling capacitances between the transceiver ground and the body is highly affected by the body configurations and has the values of 10fF – 100fF. By cascading multiple RC blocks, a complete circuit model of the human body can be constructed as shown in Fig. 3. The frequency characteristics of the human body are simulated by using the distributed RC model. Its results are compared with the measured values as shown in Fig. 4.

From the Fig 4, at the low frequency region, the body channel behaves like a high pass filter because the coupling capacitor in the return path is dominant under 8MHz. However, above 20MHz, the resistance of the human body plays more important role than the coupling capacitor. Although the return path through the capacitive coupling between the body and the external ground becomes stronger and induces larger signal with frequency, more signal power is radiated out and wasted. As a result, its S_{21} curve is bent gradually downward like the convex curve of the band pass filter. For the longer distance of the channel, the convex point is placed at the lower frequency. This is because the area exposed to the air increases resulting in more radiation with the channel length. For the step input, the output is a pulse signal with the width of about 8ns, corresponding to the bandwidth of 125MHz.

From the frequency characteristics, the human body is modeled as a band-pass filter with the bandwidth of about 100MHz and shows about 5dB attenuation. According to this investigation, the suitable frequency for the body channel communication in the human body channel is found to exist in the range of 10kHz to 120MHz. It is named as "*the Bodywire channel*" which can give the vast bandwidth for data communications in the body area environment.

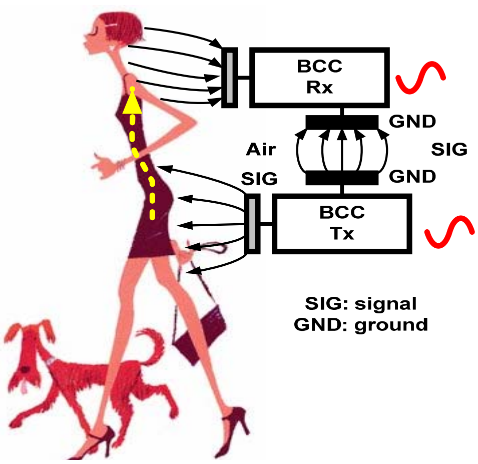

Fig. 2 Schematic Diagram of On-Body Communication System

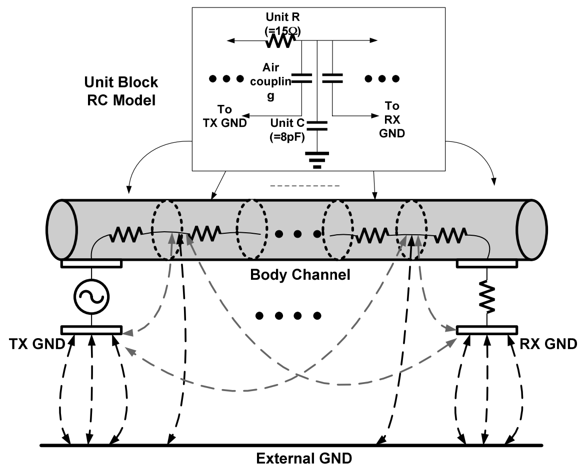

Fig. 3 Electrical Model of the Human Body

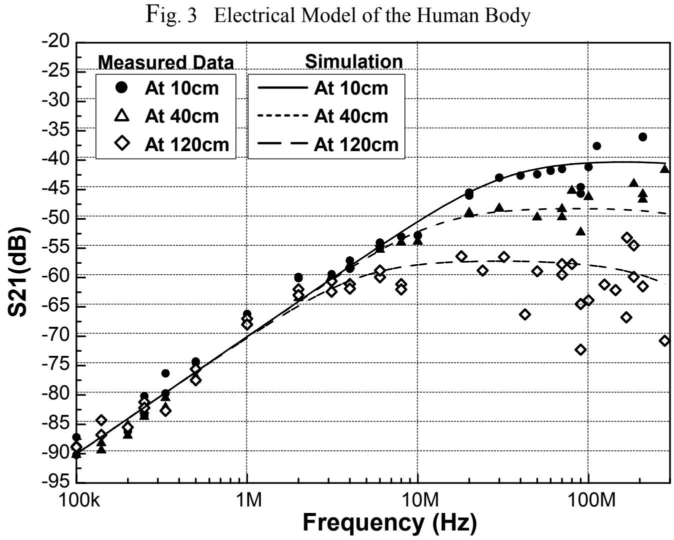

Fig. 4 Frequency Characteristics of the Human Body

III. LOW POWER TRANSCEIVERS

Based on the study of the channel characteristics of the human body, we propose a new method, the wideband pulse signaling (WBS) transceiver with a direct-coupled interface (DCI) to achieve lower power consumption and higher data rate. DCI can remove the purposeful ground electrode from the transmitter and receiver leading to simple implementation. For example, an extra ground electrode contacting the skin or a special electro-optic sensor to detect the feeble electric-field is unnecessary.

A test IC is designed, fabricated and tested in the real environment to demonstrate its feasibility and find the performance requirements for the transceiver, such as the signal detection sensitivity and power consumption[2]. The fabricated transceiver adopts the WBS technique through the *Bodywire* communication channel with DCI interface scheme.

Figure 5 shows the block diagram of the transceiver that comprises a NRZ data transmitter and a CDR-based WBS receiver. The AFE accomplishes three tasks[8]: amplifying, triggering, and level shifting. A wide bandwidth preamplifier provides sufficient amplification to a pulse signal although it is corrupted by the channel. This enables the stable triggering to positive and negative states in the following schmitt trigger circuit. Subsequently, the signal is shifted up to ground level.

A test DCI is implemented with a PCB including a single Ag/AgCl electrode powered by an alkaline battery. Figure 6 shows the measured eye diagrams of input data, recovered clock and data of the CDR circuit for 2Mb/s 2^7-1 PRBS, exhibiting the recovered clock jitter to be 1.4ns rms. The WBS transceiver chip shown in Figure 7 is fabricated using 0.25-μm standard CMOS technology and its core area is 0.85 mm^2. Its power consumption is less than 0.2mW at a single 1V supply. The AFE consumes most of the total power[8]. The measured bit error rate is less than 10^{-7} for 2^7-1 PRBS. Figure 8 shows the power loss along the distance on the body and the signal degradation at 1m distance is -20dB which is within the receiver detection level. The transmission of the MP3 file from the finger tip to the ear,headphone, is possible and will be explained in Section V.

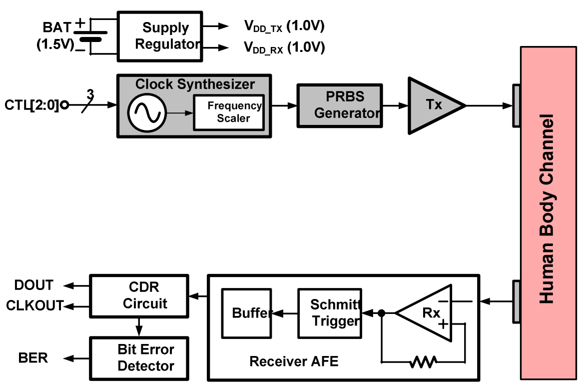

Fig. 5 Schematic Diagram of WBS Transceiver

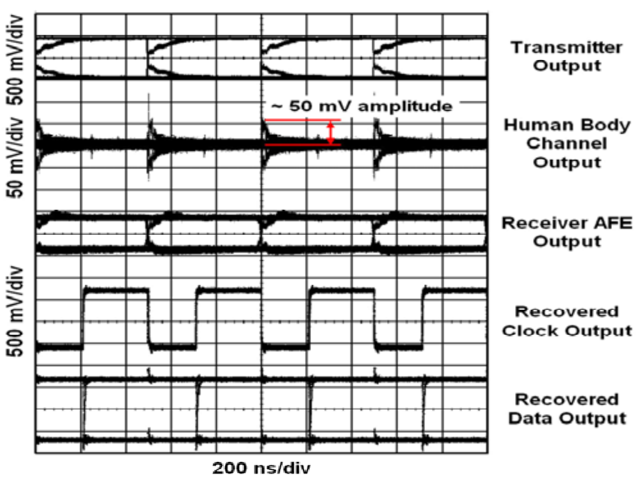

Fig. 6 Eye Diagram of WBS Transceiver Chip

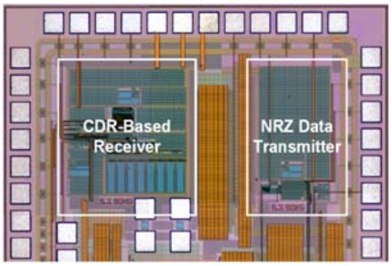

Fig. 7 Microphotograph of the WBS Transceiver Chip

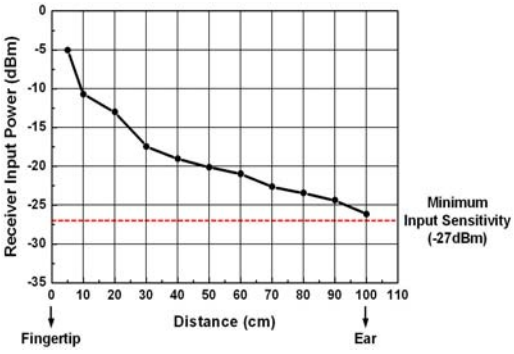

Fig. 8 Power Loss along the Distance

IV. INTELLIGENT BSN CONTROLLER

Collecting and analyzing the vital signals from the various places spread on the human body are the key issues of BSN. An intelligent network controller is required to control data traffic from the multiple simple sensor nodes. Fig. 9 shows a BSN system with one intelligent base-station for the control of all the sensor nodes for the sensing of the vital signals. Data are transmitted as a packet format which consists of 16bit header and 16×n bit payload.

In this paper, we propose an intelligent BSN controller and fabricate it into ultra low power CMOS IC. Figure 10 shows the structure of the proposed bio processor[9]. It has two modes, normal and alert. The normal mode gathers bio-signals from the sensor nodes with programmed periods and checks whether the incoming signal is in alert situation or not. The alert is issued when the signal values exceed the pre-set range. If the value is over the range, the mode is changed to alert mode and branch to the corresponding algorithm to resolve the problem.

In the normal mode, the Schedule Director (SD) requests and analyzes incoming packets, and stores bio-signal data to the Sensed Data Memory (SDM). In the mode, system clock is deactivated, and only SD and SDM work with 16.384kHz CLKSD.

If the incoming packet has the alert information, SD enables the system clock and wakes the RISC up by providing appropriate program counter value. And the RISC controls the whole system by executing the program starting from the new PC address. After the problem is resolved, the RISC powers off itself, deactivates the system clock and the system returns to the normal mode.

The SD checks the schedule for data request in every second and generates the request packet for maximum 254 sensor nodes which have independently programmed request-period. 256x16bit TCAM block is used to store and issue the schedule information instead of using 256 independent timer circuits[10].

To manage 1-day scheduling by second-to-second for 254 independent devices, using the traditional timer needs 21,945,600 clock transitions and it consumes high power. The proposed CAM scheduler, however, requires 86,400 transitions and corresponding search operations, only 0.4% of transitions. It provides 15 kinds of schedule periods, 2/5/10/20/30-seconds, 1/2/5/10/20/30-minutes and 1/2/4/8-hours, which cover most of the measuring period for bio-signal monitoring.

Each bit of the TCAM words indicates validation bit, 2s, 5s ~ 2h, 4h, 8h, respectively. The timer block generates 15bit search data according to the real-time clock. ID generator checks Match Line(ML)s starting from the CAM Word Line. If the match line is activated, it generates corresponding 8bit ID number of the sensor node and SD generates the request packet for the sensor. It checks the next ML after SD gets the requested data successfully. If the result is mismatch, it skips generating the request packet and checks the next ML[10]. Packet Analyzer gets incoming packets, detects alert information and stores the payloads to SDM.

The RISC analyzes the sensor data, executes algorithms and compresses data[11]. It has 16bit data width to handle most of bio-signal data, 3-stage pipelined Harvard architecture and the lossless data compression engine. The data compression engine reduces the amount of the sensing data such as vital signal waveforms without losing its information and saves memory space and power

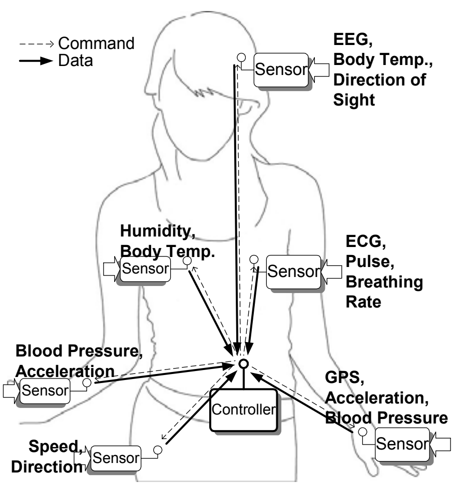

Fig. 9 Concept of BSN using On-Body Communication

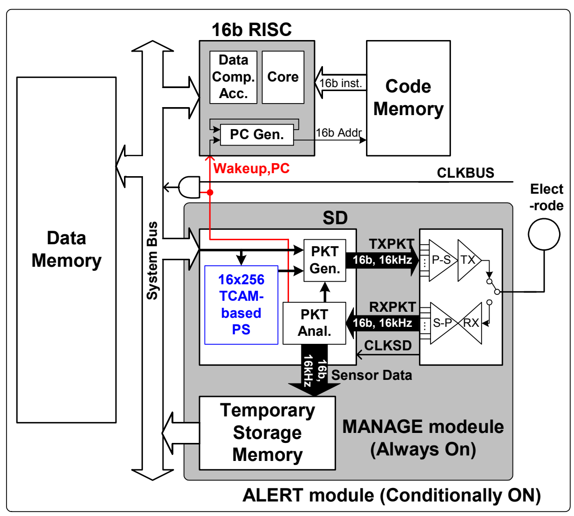

Fig. 10 Block Diagram of the Intelligent BSN Controller

consumption for data transmission. It consists of 16 x 16bit memory block which can be accessed both in vertical and horizontal ways. With the lossless data compression engine, the RISC spends 5% of clock cycle for the data compression compared with general RISCs. It consumes 2.0nJ energy to compress 16x16bit data while the state of the art low power processor requires 32.4nJ.

Figure 11 is the chip microphotograph of the proposed Bio Processor. It consists of 16bit RISC, SD, Human body communication transceiver and 3 memories, 128kb CM, 512kb CDM, 128kb SDM. The 16bit system bus with 4.194304MHz clock connects RISC, CDM, SDM and SD. RISC works as a master, accesses memories and sets SD registers. SD, HBT and write path of SDM works with CLKSD clock and the frequency can be set to 8.192/16.384/32.768kHz according to the required bandwidth mode, slow/normal/fast mode, respectively. With the normal bandwidth mode, the processor consumes 14uW in normal mode and 160uW in alert mode including leakage current.

V. BSN APPLICATIONS

There are many potential applications of the proposed on-body communication to BSN. One is the entertainment application, replacing the wire of the MP3 headphone. Fig. 12 shows a MP3 player with on-body communication transmitter and an earphone with on-body communication receiver. The user can enjoy the high quality MP3 music without any discomfort. The only short coming of this communication method is that the user should contact the electrodes of the transmitter and receiver.

Another interesting application area is the affective computing, especially detection of the emotion[12]. The physiological information such as body temperature, blood pressure and heart rate can be gathered and analyzed to get not only the medical and health information but also the emotional state and behavioural state of the user for the machine intelligences.

In this study, the temperature, blood pressure and ECG are monitored at 10 different spots on the body to get the bio information using the on-body communication, and the information is processed by the intelligent network controller to detect the emotional state of the user.

Fig. 13 shows the photographs of the intelligent controller and many sensor nodes on a human body. The BSN is composed of the 8 temperature sensor nodes(T), 1 ECG(C) or 1 blood pressure sensor node(B) and the measured data are transmitted to the controller through on-body communication link. The sensors are activated and its data are captured at the predetermined time by the controller.

The controller pre-processes the collected data $\{T_i, C, B\}$ to get the 5 statistical data such as range(min/max), means, standard deviations, slopes and comparison with predetermined reference for each sensor data. Then, the obtained 50 physiology dependent features are transferred to outside computer and reduced to 5 principal features to represent most of the features of the data sets. The training data have been gathered from multiple subjects and grouped into their emotion types with afterward user interviews. The testing boundaries are obtained from the training sets and applied to the classification of the emotion. We tentatively categorize the emotion into 4 typical states, Joy, Sadness, Fear and Anger. The bottom of Fig. 13 is an example of the emotion detection predicted with the data collected through on-body communication. Currently, more detail studies incorporating the classification algorithm on the intelligent controller and increasing the accuracy of the emotion detection are under going[13] and will be reported.

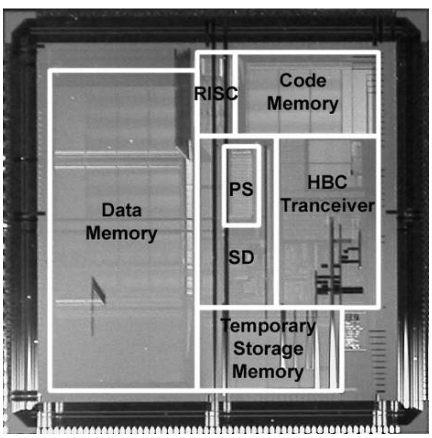

Fig. 11 Photomicrograph of the BSN Controller Chip

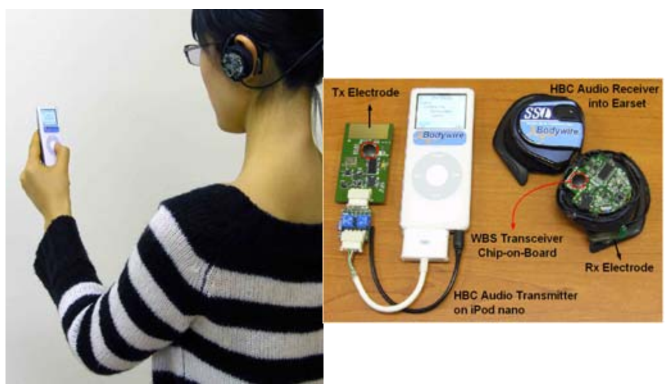

Fig. 12 MP3 File Transfer using On-Body Communication

VI. CONCLUSIONS

We introduced and explained a BSN architecture, a communication chip, a BSN controller chip and its applications. The electrical characteristics of the human body surface are investigated for the use of the communication channel. 10KHz-100MHz frequency band, named as 'bodywire', is found to be most effective in the wireless on-body communication. We did not use any intentional ground electrode for the capacitive coupling and this simple structure is called DCI. A CMOS transceiver chip with the on-body communication is designed and fabricated. It can achieve 2Mbps with 0.2mW power consumption. The architecture of the intelligent BSN controller is proposed and fabricated with CMOS. It has a 16b RISC and a schedule director with TCAM. It can separately control 254 sensor nodes and consumes 14uW in normal mode and 160uW in alert mode including leakage current. The fabricated chip is used to transmit MP3 data from the finger tip to the earphone to enjoy high fidelity music. In addition, the proposed BSN system is used to detect the emotion of the user by classifying the data from the sensor nodes transmitted through on-body communication channel.

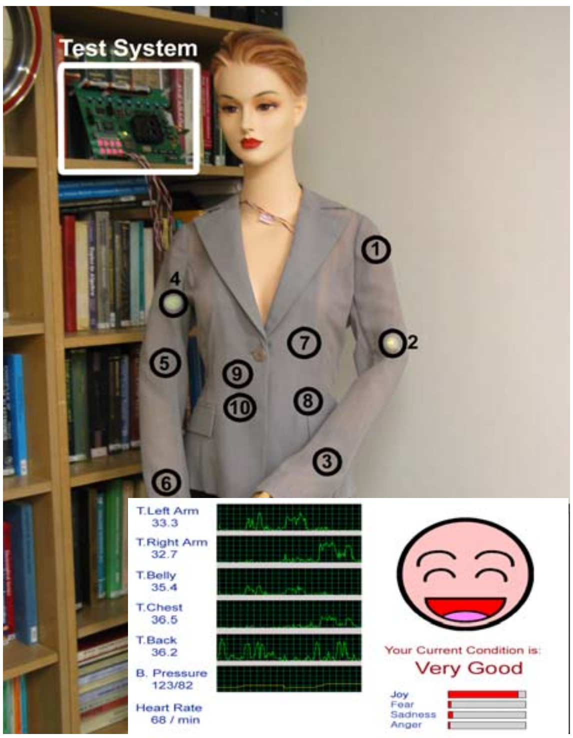

Fig. 13 BSN of On-Body Communication and an Example of Emotion Detection

The on-body wireless communication is convenient and effective for the BSN, and has many potential application areas such as entertainment, healthcare and even affective computing.

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