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Body Sensor Networks Powered by an NFC-coupled Smartphone in the Pocket

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***Abstract*— This paper proposes a body sensor network (BSN) on clothing that is wirelessly powered by a smartphone in a pocket. The network consists of a host device and multiple sensor nodes, which are distributed on a wear and are electrically connected with conductive threads. The smartphone with a built-in near field communication (NFC) feature powers the host, which is fixed at the pocket. These devices are wired to a special cloth embroidered with conductive threads by using a special connector consisting of a pin & socket without one-to-one wiring. In the proposed BSN, the host device and the smartphone are coupled via NFC radio within the pocket. Energy harvesting with NFC radio wave requires maintaining antennas within several centimeters to obtain enough power. Positioning and fixing of the smartphone is required within the pocket. A proposed host device can expand the range of energy harvesting by using multiple antennas and a power aggregation circuit. The experimental results demonstrate the feasibility of the batteryless BSNs system.**

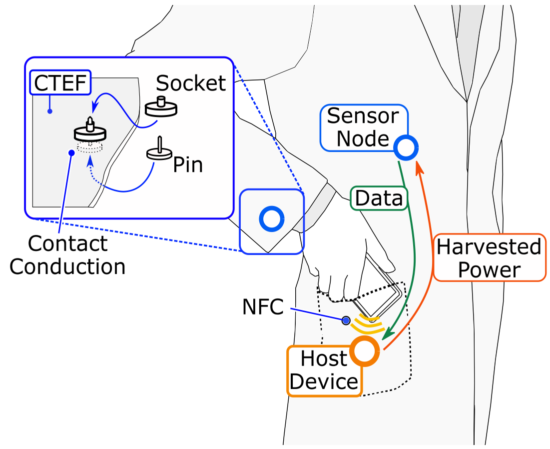

Figure 1. A batteryless BSN using a NFC-coupled host device and a CTEF. This figure is cited from [8].

I. Introduction

Body Sensor Networks (BSNs) [1], which gathers data from worn sensor nodes to a host device, is a promising technology for health care [2], fitness [3], and so on. A batteryless sensor node can reduce the burden on the wearer because there is no trouble of charging and replacing batteries.

A wired BSNs can eliminate the battery of the sensor nodes. A conductive-thread embroidered fabric (CTEF), which is a wired transmission path with a two-dimensional spread, can construct it without one-to-one wiring. In the wired connection BSNs, the sensor nodes can transmit/receive the data/power to/from a host device [4][5]. However, the host device still needs batteries for multiple sensor nodes and the host device itself.

In this paper, we propose a batteryless host device. The proposed host device can transmit/receive the data/power to/from a smartphone in the pocket via a Near-Field-Communication (NFC) [6]. Fig. 1 shows the overview of the proposed batteryless BSNs.

In Fig. 1, multiple batteryless sensor nodes are connected to the CTEF via a pin & socket connector without one-to-one wiring. The same is true for a batteryless host device connected in the pocket. The power source of the host device and the sensor nodes is obtained by harvesting the NFC radio waves emitted from a smartphone in the pocket.

NFC can remove the battery of the host device. The power consumption of an NFC transponder is about 10 mW [7]. Energy harvesting (EH) using NFC radio waves (NFC-EH) can acquire 40-50 mW as experimentally demonstrated in Section Ⅲ of this paper.

NFC-EH requires maintaining antennas within several centimeters to obtain enough power for the host device and sensor nodes. Therefore, the users need to check the direction of a smartphone for positioning of the antennas when putting it in the pocket. And the pocket must be the same size as smartphone to prevent misalignment.

To solve this problem, we propose a host device that can expand the range of NFC-EH by using multiple NFC antennas. Covering the inside of the pocket with multiple NFC antennas does not need the positioning or fixing the smartphone.

In the next section, the circuit diagram of the NFC-coupled host device and the connection method of the pin & socket connector are described. The experimental verification is presented in Section Ⅲ. Finally, we will conclude this paper in Section Ⅳ.

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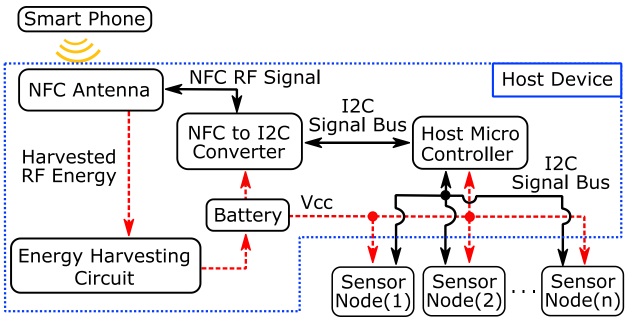
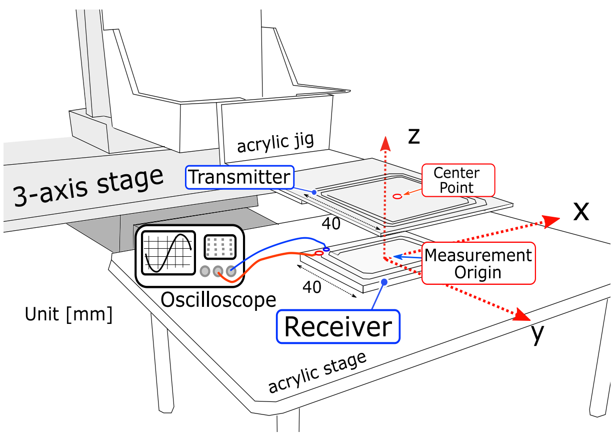
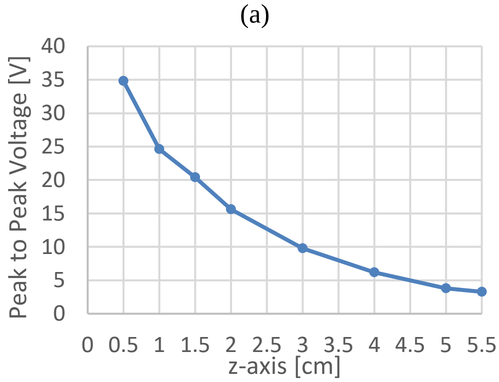


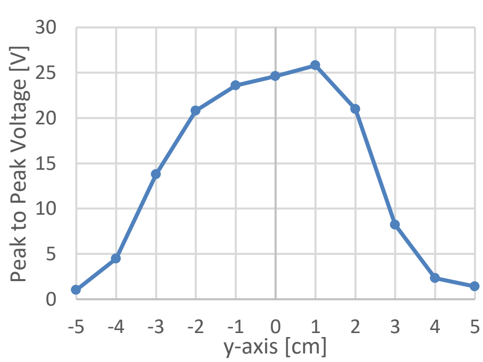
Figure 2. A system model of the host device.



(a)



(b)



(c)

Figure 3. (a) Preliminary experimental setup, (b) Received peak-to-peak voltage when moving vertically ($x = y = 0$), (c) Received peak-to-peak voltage when moving horizontally ($y = 0$, $z = 1$). This figure is cited from [8].

The contents of this paper will be published in Japanese [8]. This paper is the first publication in English.

II. Circuit Diagram of NFC-coupled Host Device

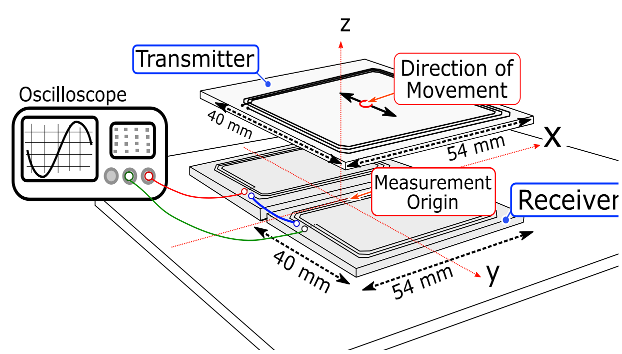
In this paper, we developed a prototype of a NFC-coupled host device that can expand the range of the NFC-EH by increasing the number of NFC antennas. A system model of the host device was shown in Fig. 2. We focus the NFC-EH system (red dotted line in Fig. 2). The communication system (black line in Fig. 2) is still in the concept stage. An I2C communication technology via the CTEF was proposed in [9].

A preliminary experiment was conducted to confirm the range of NFC-EH with one antenna. The received peak-to-peak voltage was measured.

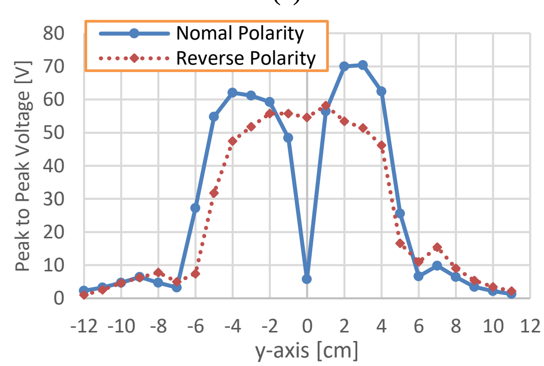
The experimental setup was shown in Fig. 3 (a). The center of the receiving antenna was set as the measurement origin. And it fixed to the acrylic stage. The transmitting antenna fixed to the 3-axis stage via an acrylic jig was moved in the y and the *z*-direction shown in Fig. 3 (a).

Fig. 3 (b) shows that the received peak-to-peak voltage is halved or less every time the distance of *z*-axis becomes 2 cm apart. Fig. 3 (c) shows that the received peak-to-peak voltage sharply decreases with misalignment of antenna width (40 mm) or more.

Next step, the receiving NFC antenna was expanded to two. The experiment was continued by arranging it as shown in Fig. 4 (a). The two NFC antennas are connected with the normal polarity and the reverse polarity in series. Fig. 4 (b)



(a)



(b)

Figure 4. (a) Experimental setup. (b) Received voltage waveform. The transmitter was moved in the y direction with x = 0 cm, z = 1 cm. This figure is cited from [8].

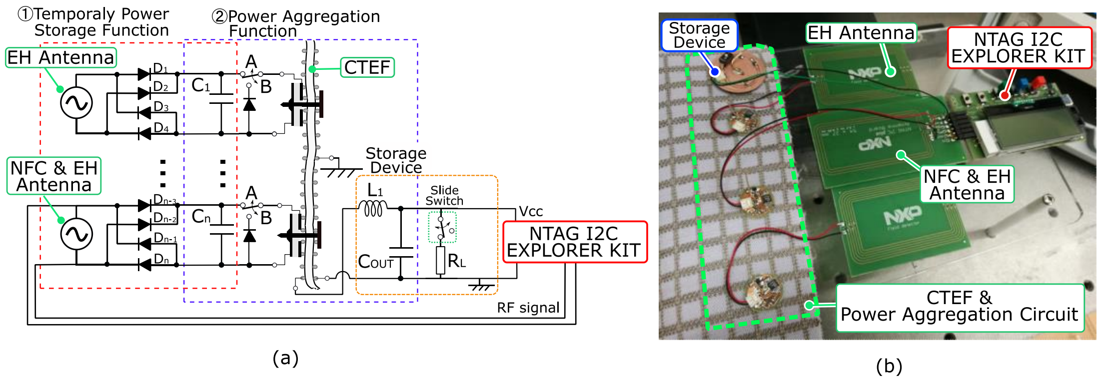


Figure 5. (a) Circuit diagram of the host device. (b) Prototyped host device. This figure is cited from [8].

shows the received peak-to-peak voltage when the transmitting antenna is moved in the y direction.

The received voltage waveform of each antenna is different in phase and voltage. The energy loss occurs by canceling each other. The result of normal polarity connection shows that a null point occurs when *y*-axis is 0.

When the one receiving antenna is connected with the opposite polarity, the null point does not occur at the same point. On the other hand, the peak-to-peak voltage of the reverse polarity is lower than the normal polarity when *y*-axis is from -6 cm to -2 cm or from 2 cm to 6 cm.

To avoid this problem, we use the power aggregation circuit proposed in [10], [11]. The circuit diagram of the proposed host device is shown in Fig. 5 (a).

The power aggregation circuit has the following two functions: 1) a temporary power storage function (the switch position B); 2) a power transmission function using a coil and a switch circuit (the switch position A).

During temporary power storage, the antenna is electrically disconnected from the circuit by the switch. Thus, it can be charged without interference from other antennas.

When current flows between the capacitors connected in parallel, a part thereof is lost as heat. In the power aggregation function, the energy in the capacitor C_1 is sent to the capacitor C_{out} of the storage device without loss by passing through the coil and the switch.

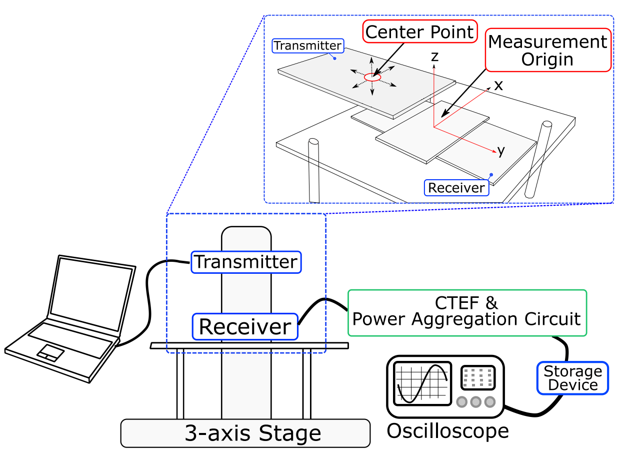


Figure 6. Experimental setup. This figure is cited from [8].

The NFC antennas with the power aggregation circuits are connected to the CTEF via a pin & socket connector. A pin & socket connector simultaneously realizes penetration fixing and contact conduction at arbitrary positions of the CTEF. Conductive thread is embroidered in mesh on both sides of cloth. A metallic socket is fixed and conducted by soldering to the surface of the double-sided copper clad board. Conductive thread on the top and the back side of the cloth respectively contact with the backside of the board and the pin.

Notably, the CTEF in the pocket used to connect the antenna is electrically independent of the CTEF of other areas.

The prototyped host device is shown in Fig. 5 (b). Each antenna is connected to a pin & socket connector on which a temporary storage capacitor C_1 and switch control IC (LTC3588-1, linear technology [12]) are mounted.

For the communication part, a commercially available development board (NTAG I2C plus Explorer kit, NXP [13]) was used. NTAG I2C converts the NFC signal into an I2C signal and acquires various sensor information on the board via I2C.

III. Experiment

In this section, we evaluate the extension of NFC-EH possible range using multiple antennas and power aggregation circuit. The experimental environment is shown in Fig. 6. The measurement origin is the center of the antenna for communication and EH. A charging speed and communication range were measured.

The charging speed W_{charge} is expressed as

$$W_{charge} = \frac{E_{storage}(t_{end}) - E_{storage}(t_{start})}{t_{end} - t_{start}}, \tag{1}$$

where

$$E_{storage}(t) = \frac{1}{2} C_{out} V_{storage}^2(t). \tag{2}$$

$E_{storage}(t)$ denotes the energy charged in C_{out}. And $V_{storage}$ denotes the voltage of C_{out}. t_{start} and t_{end} denote the charging start and end time.

While the slide switch of the storage terminal is turned on, the charge of C_{out} immediately flows to ground through R_L. Thus, the time when the switch is turned off is defined as the charging start time. And the time when the rise of $V_{storage}$

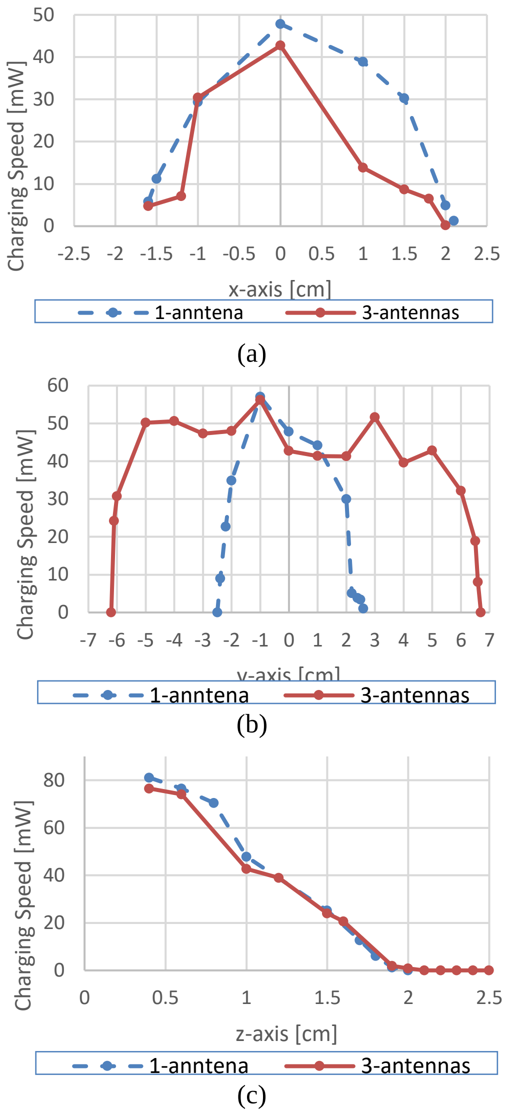


Figure 7. Charging speed when moving the transmitter in each direction. This figure is cited from [8].

stops is defined as the charging end time. $V_{storage}$ is measured by the oscilloscope.

The results of charging speed are shown in the Fig. 7. As no antennas were added in the x-axis and *z*-axis directions, similar results were obtained in the two cases. In the *y*-axis direction, the distance that can charge 20 mW or more extended from 4 cm to 12 cm. Since the outputs of the adjacent antennas are added, the charging speed has increased more than in the case of one antenna at the boundary between the antennas near y = ± 2 cm.

The communication range is defined as the distance until the communication between transmitter and the NTAG Explorer kit is interrupted. It was 2 cm each in the x, y, z direction. While the proposed method extends the range of NFC-EH, the communication range remains unchanged.

IV. Conclusion

We proposed a BSNs scheme which use the NFC-coupled smartphone in the pocket as the power source of a host device and multiple sensor nodes. These devices are wired without one-to-one wiring by using pin & socket type connector and a conductive thread embroidered fabric. The host device and the smartphone are coupled via NFC radio within the pocket. Energy harvesting using NFC radio requires the maintaining NFC antennas within several centimeters. The batteryless host device, which has the power aggregation circuit and multiple NFC antennas, solved the above problem. Positioning and fixing of the smartphone is not required on the area where the multiple antennas are arranged in the pocket.

The experimental result shows that the feasibility of the batteryless BSNs system in the case where the direction and position of the smartphone are not fixed in the pocket.

Acknowledgment

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