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メタデータ	言語: eng 出版者: 公開日: 2017-10-03 キーワード (Ja): キーワード (En): 作成者: メールアドレス: 所属:
URL	<a href="https://doi.org/10.24517/00009812">https://doi.org/10.24517/00009812</a>

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# Flexible Network Infrastructure for Wearable Computing Using Conductive Fabric and Its Evaluation

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## Abstract

*Numbers of devices are distributed in the environment in wearable and ubiquitous computing systems, and all of such devices need power supply and communication ways as well as flexibility of placement. Both wireless and wired communication systems intrinsically contain the problems in power supply or flexibility of placement.*

*In this paper, we introduce the flexible network infrastructure for wearable computing systems, named as TextileNet, and experimental results of its evaluation. TextileNet uses the wear both of sides of which are made of conductive fabric as electrodes. On this year, the power is supplied from a battery, and the devices are attached by sticking so that electric contact can obtain the sufficient power and communication way on the wear's surface. This paper describes the implementation and evaluation of the TextileNet system.*

## 1. Introduction

Based on the drastic development of computers and network systems, a new paradigm of computing system, ubiquitous computing is widely attracted and studied. A number of devices, such as sensors and computers, are distributed in the environment, and the integration of them enables a new paradigm of computing system.

The wearable computing systems are also recently widely studied as a kind of ubiquitous computing[1, 2]. Users can install the devices, such as computers, sensors or displays, on their wear, and the integrated system of these devices enables the novel usage of computing. A lot of studies on the applications of wearable computing systems are widely reported such as life vest

in arctic environment[3, 4], firefighters' wear[5, 6], support system for racing team[7], combat jacket[8], traveler's support system[9], motion capture system[10, 11], nurse support system[12], 'life log' system[13, 14, 15], medical monitoring system[16, 17, 18], rescue system for buried person by the avalanche[19], location identification system[20], and so on.

The common problems in wearable computing systems are summarized as follows.

- A lot of devices exist on the wear.
- The devices need to communicate each other.
- The devices require the power.

There are two possible physical methodologies for implementation of system configuration. One is the wired system, and the other is the wireless system.

In the wired system, the devices are connected each other by wires which provide both power supply and communication channels. The wired systems essentially have a problem in wiring. It is a burden for the user to install the wires at initial, and it is more serious and fatal to arrange the physical layout of the devices, since the complicated wires exist on the wear.

In the wireless system, the communications among devices are carried out by the wireless channels (radio, infrared and so on). Therefore, the problem in the wired systems are solved and users can install and arrange the layout of devices more flexibly. However, the wireless systems have another essential problem; power supply problem. All the devices require the power supply for their operations, but in the wireless system, there are no power supply cables for devices. The battery operation is one of the solutions for power supply, but the devices cannot be permanently in operation for the finite battery life. This battery problem becomes fatal especially when wearable computing systems are

extended, since as the number of the devices increases, it becomes difficult to maintain the batteries of so many devices for a long period of operation time.

As described above, the wearable computing systems require the power supply and the communication network, while neither the conventional wired nor the wireless systems cannot completely provide them with keeping the flexibility of installing and arranging layout of devices.

We've been developing a new architecture of flexible network infrastructure for wearable computing systems using conductive fabric, which is named as "TextileNet[21, 22]." TextileNet provides all the devices installed on the wear both sufficient power supply and communication channels, while keeping the flexibility of installing and arranging layout of devices. Users can install the adequate devices according to the applications of TextileNet, and sufficient electric power for operation as well as communication channels can be supplied to the devices at the same time. As described here, TextileNet is expected to become an infrastructure for any kind of wearable computing systems, which is essential for further development and spread of wearable computing system in a personal usage.

In this paper, we describe the idea and implementation of our TextileNet system as well as its evaluation.

## 2. Related Works

There are a lot of related works on the new wearable computing systems.

'Networked Vest'[23] uses conductive fabric for both sides of the wear, and the devices attached on this vest have DC-PLC (Power Line Communication) modem in order to obtain DC power from single power supply, as well as modulated analog signal communication. Although the attached devices can be supplied sufficient power, communication signals are broadcasted to whole the wear as analog signals, and there are no arbitration mechanisms implemented for point-to-point communication. The details of electric characteristics are discussed and evaluated, but it cannot provide the wide band-width of communication channels.

'Push&Pin' system[24] aims at the network system on a pair of conductive surface, including conductive fabric wear as well as the wall, but it employs 1-Wire[25] system for physical implementation. In the 1-Wire system's specifications, the flexibility of network configuration is limited as master-slave architecture, and the communication speed is as slow as approximately 1200[bps], that is not fast enough for practical wearable computing systems.

'PinPlay' system[26] also uses a pair of conductive

surface for power supply in order to build distributed computing systems, but the communications among devices are implemented by wireless manner.

C.Randell et al.[27] implements the wear with a pair of conductive fabric for power supply, electro-magnetic detector, and thermal source for display, but there no implementation on networking system.

There are other groups of wearable computing system without complicated cables.

'E-textile'[28] combines a conductive thread and an insulator thread to weave a cloth for the wear, and the conductive thread forms the embedded wiring. It can implement a cable-less wearable computing system for the specified applications, but it is impossible to arrange the layout of devices.

'Electronic Textiles'[29] uses a conductive thread with insulator coating for horizontal and vertical directions as well as an insulator thread. The devices are attached at the cross point of the horizontal and vertical conductive threads in order to form the electronic circuit. It can implement the cable-less wearable computing system, but it is impossible to obtain the complete flexibility of installation, since the positions of the devices are restricted to the cross points of conductive threads.

A lot of studies on wearable computing system with complicated cables are reported[30, 31]. Medical monitoring system is one of the most important applications of wearable computing systems. There are medical monitoring systems with complicated cables[32, 33] and without cables[34], but all of them have the serious problems in either complicated wiring or power supply as described in the previous section.

There is wireless communication systems with wireless power supply. CoBIT[36] system uses the solar cell as the receiver, and the power and the modulated signal are provided to the transmitter. However, only a few milli-watts can be supplied to its devices due to the restrictions of light intensity. RFID systems[35] have the variations of passive tag which receives the electric power via the electro-magnetic wave from the transmitter as well as communication signal, but the available power on the devices is also restricted by the strength of electro-magnetic wave.

## 3. Implementation of TextileNet

TextileNet system described in this paper has the following features compared with the existing systems based on the newly developed circuitry.

- Cable-free
- Comfortable wear with conductive fabric



**Figure 1. Developed wear using conductive fabric.**

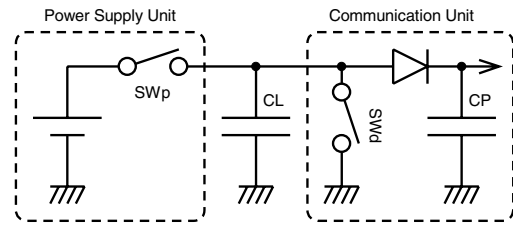


**Figure 2. Electro-magnetic shield cloth.**

- Free installation on the wear by pins
- High communication ability (Point-to-point)
- High power supply ability ( $\sim 3W$ )

### 3.1. Conductive fabric and wear

We have developed electric conductive wear for the TextileNet system as shown in Fig.1. This wear consists of three layers; the conductive fabric for both outer sides of the wear with one insulator fabric between them. These three layers of fabrics are sewn by using a conventional sewing machine. Conductive fabric employed here is a product for the electro-magnetic shield cloth whose surface resistance is about  $0.5\Omega/\text{sq.}$ , as shown in Fig.2. This conductive fabric is made of



**Figure 3. Circuit architecture of data communication and power supply unit of TextileNet.**

meshed conductive thread, and it is adequate for comfortable fit, which is a ‘basic function’ of wear.

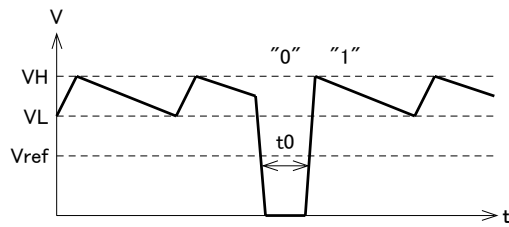
The evaluation of the electronic characteristics of this wear including in the practical situations is described in section 4.

### 3.2. Communication unit and power supply unit

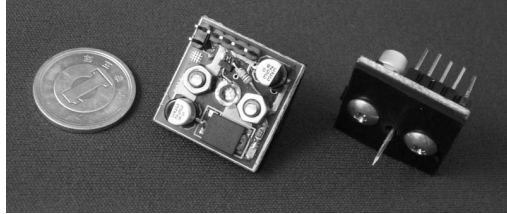
The 1-Wire system[25] is a wiring system using a pair of cables which provide power supply and communication channels. In the 1-Wire system’s specifications, the flexibility of network configuration is limited as master-slave architecture, and the communication speed is as slow as approximately 1200[bps], that is not fast enough for practical wearable computing systems.

From the application point of view, the devices attached on the wear should be physically small enough to suit the comfortable wearable computing application. In order to implement such small communication devices, we employed the DC-based architecture for power supply with occasional pull-down strategy for communication. We newly designed the power supply and communication circuit architecture using a pair of electrodes as shown in Fig.3. It is composed of one power supply unit, the communication units installed on the TextileNet, and a pair of electrodes as the surfaces of the wear.

The energy supplied from the power supply (the battery connected to the power supply unit) is charged in the power capacitor,  $C_P$  at each communication unit, and the voltage of the surface of the wear,  $V_L$  is controlled to keep approximately 15V by the power supply unit as shown in Fig.4. When one of the communication units starts to send some data,  $V_L$  is pulled-down to low voltage of 0V for a certain moment,  $T_0$ , and all the communication units on the TextileNet receive this data of ‘0’ simultaneously. At this moment, the power supply unit detects this drop of  $V_L$  and turns the pull-up switch off. This pull-up switch is again



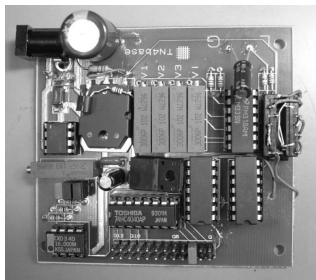
**Figure 4. Voltage wave of developed TextileNet system.**



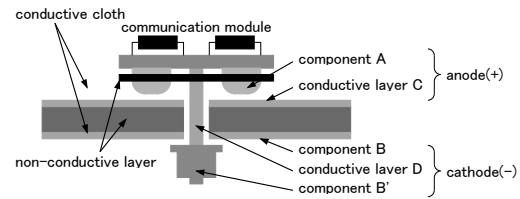
**Figure 5. Developed communication unit.**

turned on after a certain term of  $T_1$ , where  $T_0 < T_1$ , in order to continue power supply to each device. The energy of communication units for the term of  $V_L = 0$  is supplied by the power capacitor,  $C_P$  in each communication unit. The data of '1' can be represented as the high  $V_L$ , and data transmission can be initiated by the start bit as the first '0', as a conventional asynchronous serial communication.

The functions required for each communication unit are (1)power regulation, (2)one bit transmission by pull-down switch, and (3)data receive, which enables to implement the small size of the communication device. Figure 5 shows a developed communication device whose size is  $20\text{mm} \times 20\text{mm}$ , and it has the power supply capability of up to 3W. Figure 6 shows a developed power supply unit. The communication speed of



**Figure 6. Developed power supply unit.**



**Figure 7. Structure of electric contact.**

**Table 1. Devices used in the evaluation experiment of TextileNet.**

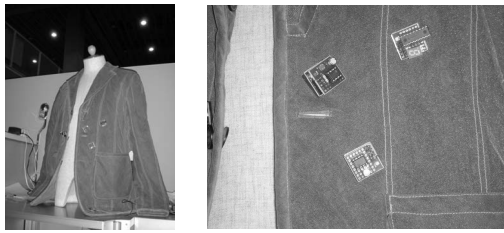
Device	Function	Data Communication
#0	photo sensor	'0' or '1' to device #2
#1	photo sensor	'0' or '1' to device #2
#2	LED display (Red&Green)	data from device #0&#1
#3	PC connection	one character to device #4
#4	LED display (numeric)	data from device #3

this prototype devices is designed to become 9600[bps] in order to keep the enough margin of operation. The developed prototype system of TextileNet has the communication ability of one byte broadcasting, and arbitration of data transmission and error correction can be implemented by the higher protocol layers in our future work.

Both the communication units and the power supply unit should be electrically connected to both side of the wear by sticking. Figure 7 shows a structure of the developed contact. The unit is contacted to the outer side of the wear by the electrode of the unit, and to the inner side of the wear by the pin with insulator and snap.

### 3.3. Operation of TextileNet system

We carried out the evaluation operation of the developed TextileNet system. We've built five devices using the communication units as shown in Tab.1. Two photo sensors detect the change of brightness, and send the information to the LED display device. The change of the brightness on each photo sensor is reflected to the red and the green LEDs on the LED display device. The PC connection device receives the character of '0' to '9' from the PC using EIA232, and the data



**Figure 8. Test usage of TextileNet.**

is sent to the LED numerical display device to display it. These devices are installed on the TextileNet wear as shown in Fig.8, and we have confirmed they are operational. The devices are also in operation when the positions on the wear are changed.

#### 4. Evaluation of wear

We have evaluated the electric characteristics of the developed wear with conductive fabric in the practical situations.

The electric resistance of the surface and the capacitance between both surfaces of the wear were measured by LCR meter (Hewlet Packard 4284A).

The electric resistance was less than  $18[\Omega]$  when dry, which is at both sleeves, and it decreased to approximately  $1/3$  when wet, as in rain.

The capacitance was up to  $9[\text{nF}]$  when dry, and it increased to  $22[\text{nF}]$  when wet by sweat.

The communication speed of the developed communication unit is limited by the time constant of charge and discharge. Based on the measured resistance and capacitance, the upper limit of the communication speed is expected to be up to  $1/(18[\Omega] \times 22[\text{nF}]) = 2.5[\text{Mbps}]$  in the worst case of practical situation, dry surface and wet by sweat.

#### 5. Conclusion

In this paper, we described the idea, and implementation of a new flexible network architecture which is named as TextileNet. We also described the experimental results of its evaluation. It has the merits of high capability of communication and power supply, as well as a flexibility of device layout and simple circuit architecture. We developed the prototype system on the wear as an example, and evaluated their operations in the developed TextileNet system.

The developed TextileNet system is expected to become an infrastructure; its usage is not specified for a

certain application since both the power supply problem and wire complication problem have been solved.

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