Flexible Network System for Wearable Computing Using Conductive Fabric

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1. Introduction

According to the drastic development of computers and network systems, a new paradigm of computing system, the wearable computing systems is recently widely studied[1, 2]. Users can install the devices, such as computers, sensors and displays, on their wear, and the integrated system of these devices enables the novel usage of computing.

The common facts 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; the wired and the wireless systems.

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[3, 4]." 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 out TextileNet system as well as its evaluation.

2. Related Works

There are some related works on network system for wearable computing system using conductive fabrics.

'Networked Vest'[5] 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[6] 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[7] 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[8] 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.[9] 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.

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
- Free installation on the wear by pins
- High communication ability (Point-to-point)
- High power supply ability (~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 0.5Ω/sq. This conductive fabric is made of meshed conductive thread, and it is adequate for comfortable fit, which is a 'basic function' of wear.

Figure 1. Developed wear using conductive fabric.

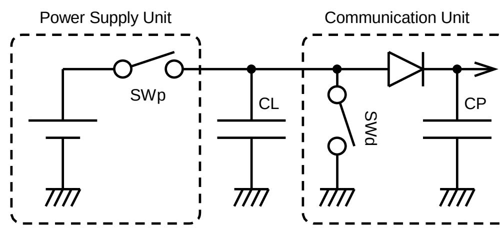


Figure 2. Circuit architecture of data communication and power supply unit of TextileNet.

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[7] 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.2. It is composed of one

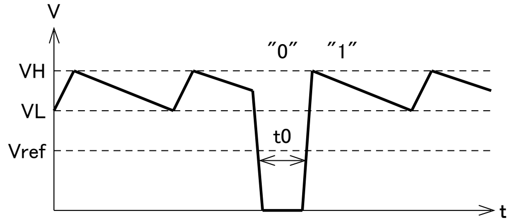
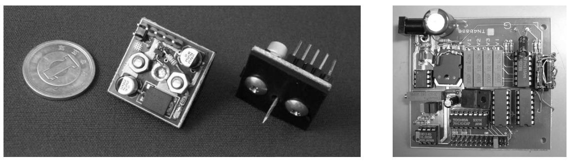


Figure 3. Voltage wave of developed TextileNet system.



(a) (b)

Figure 4. Developed communication unit(a) and power supply unit(b).

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.3. 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 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 4(a) shows a developed communication device whose size is 20mm×20mm, and it has the power supply capability of up to 3W. Figure 4(b) shows a developed power supply unit. The communication speed of 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.

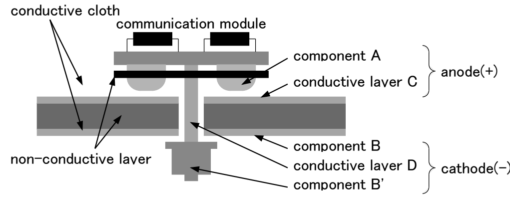


Figure 5. Structure of electric contact.

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	data from device #0&#1
#3	PC interface	one character to device #4
#4	LED display	data from device #3

Both the communication units and the power supply unit should be electrically connected to both side of the wear by sticking. Figure 5 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 is sent to the LED numerical display device to display it. These devices are installed on the TextileNet wear as shown in Fig.6, and we have confirmed they are operational. The devices are also in operation when the positions on the wear are changed.

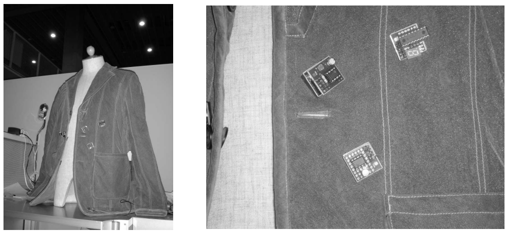


Figure 6. Test usage of TextileNet.

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 maximum electric resistance was approximately 18[Ω] when dry, which is the resistance between both sleeves of the wear. The electric resistance decreased to approximately 1/3 when wet, as in rain. Thus, the maximum resistance in the practical situation is expected to be 18[Ω].

The maximum capacitance between both sides of the wear was approximately 9[nF] when dry. The maximum capacitance increased up to 22[nF] when wet by sweat. Thus, the maximum capacitance in the practical situation is expected to be 22[nF].

The upper limit of communication speed in the developed communication unit determined by the time constant of charge and discharge. Based on the measured resistance and capacitance at practical conditions described above, the upper limit of the communication speed is expected to be up to $1/(18[\Omega]\times 22[\mathrm{nF}]) = 2.5[\mathrm{Mbps}]$ 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 uage is not specified for a certain application since both the power supply problem and wire complication problem have been solved.

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