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The Smart Patches and Wearable Band (W-Band) for Comfortable Sleep Monitoring System

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***Abstract*—The Smart Patches and Wearable Band (W-Band) are proposed for comfortable sleep monitoring system which recognizes and diagnoses sleep disorders. By using Planar Fashionable Circuit Board (P-FCB) techniques, the Smart Patches are implemented with the plain fabric patch so that it can have light weight and small size. And the stretchability of the W-Band can achieve user convenience, low manufacturing cost, and low power consumption all at once. The data display program is developed on the external PC so that the user can check the monitoring result after wake-up. The proposed sleep monitoring system is fully implemented and tested on the human during normal sleep.**

I. Introduction

Sleep consumes almost 1/3 of human lifetime and has been regarded as one of the important factors for the better quality of human life [1]. Since the inadequate sleep can cause several personal and social problems such as concentrating difficulty or motor vehicle accidents [2], it should be detected and treated as soon as possible. For the primary care of sleep disorders, the recognition and diagnosis are particularly important. The polysomnography, or sleep study, is the most effective way to analyze the sleep [3]. It monitors the bio-signals from the human body, and collects, transmits, and analyzes them to define the sleep stages. Its results can be used for diagnosis of the sleep disorders. Until now, this should be performed at a hospital with bulky devices during the sleep of at least one night. But the sleeper cannot sleep well due to the unfamiliar surroundings and uncomfortable devices. To improve the quality of the measurement and user convenience, several home sleep monitoring systems have been developed for the polysomnography [4-5]. They monitor the bio-signals from 3 to 14 channels, and wirelessly transmit all data to the external station. Although they open the door for home sleep monitoring, they still cannot provide enough comfort during sleep for users because the huge battery is required due to large power consumption of wireless communication, which results in the cumbersome size (> 49mm(W) x 19mm(L) x 6mm(H) per sensor, [4]) and heavy weight (> 210g, [5]). Moreover, they are implemented on the rather stiff board such as printed circuit board (PCB) or flexible circuit board (FCB) so that the sleepers feel hard by them.

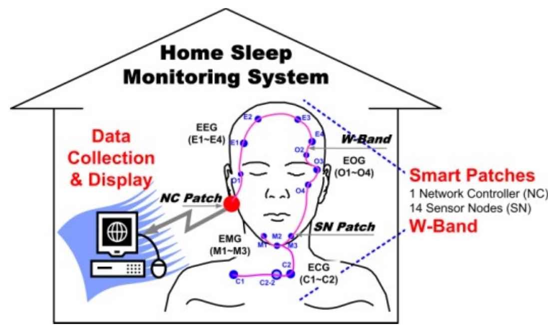

Fig. 1. Proposed Sleep Monitoring System

In this paper, a new system for comfortable sleep monitoring will be proposed with the help of the Planar Fashionable Circuit Board (P-FCB) technology [6]. It consists of 15 Smart Patches on the human skin, and the Wearable Band (W-Band) between them as shown in Fig. 1 and [7]. Since they are implemented on the fabric, it does not make users feel hard. And stretchability and wearability of W-Band can reduce the system power consumption without degrading the user convenience, so the weight overhead due to the huge battery is also eliminated. After finishing the measurement, a user can check the bio-signal data through the proposed display interface with the low power transceiver in [8]. It stores and displays the data from 14 sensors separately in order for users to see and check their bio signals in the highly visible formats.

The rest of this paper is organized as follows. In section II, the Smart Patches for either bio-signal sensing or network control will be presented. And the Wearable Band (W-Band) for connecting Smart Patches will be shown in section III. Section IV represents the data display interface on personal devices for users. Finally,

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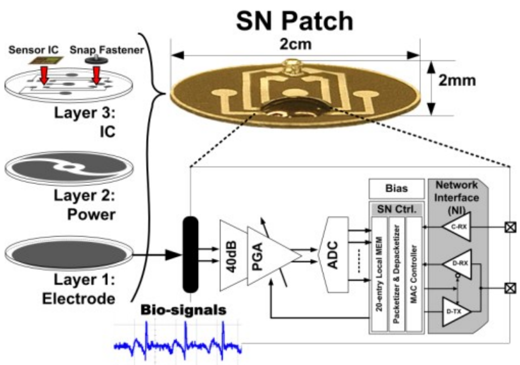

Fig. 2. SN patch for bio-signal sensing

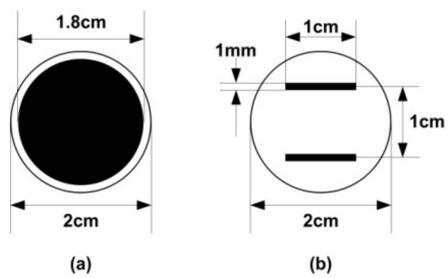

Fig. 3. (a) Single electrode for ECG, EEG, and EOG
(b) A pair of electrode for EMG

Table I. Gain and bandwidth setting for each bio-signal

Bio-signal	Gain	Bandwidth
ECG	48dB	0.4-300Hz
EMG	54dB	0.4-300Hz
EOG	54dB	0.4-40Hz
EEG	60dB	0.4-100Hz

the conclusions will be made in section V.

II. SMART PATCHES

There are two types of Smart Patches. One is to monitor the bio-signal from human body (*SN patch*), and the other is to manage the network of the proposed sleep monitoring system (*NC patch*). Both of them are implemented on the multi-layered fabric patch based on P-FCB technology in [6].

A. SN patch for Bio-signal Sensing

There are 14 SN patches in the proposed system. The optimally designed IC in [7] is integrated in each patch, so that it can monitor the bio-signals such as ECG, EMG, EEG, or EOG from human body. Fig. 2 shows the structure of the SN patch. It consists of 3 layers; the electrode, the power, and the circuit integrating IC. The electrode layer is varied according to the types of the bio-signals that each patch monitors. For example, if one SN patch monitors the ECG, EEG or EOG signal from human body, its electrode has only single pattern as shown in Fig. 3(a). The reference electrode is used to measure the potential differences among attached points. Meanwhile, the SN patch for EMG signal measurement is differed from them. Since the EMG signal is defined as the potential difference between nearby two points on the same muscle, one SN patch has a pair of electrode as shown in Fig. 3(b). In the P-FCB technology, the minimum wire width and wire spacing between adjacent lines is 100μm and 200μm, respectively [6]. Therefore, the accurate measurement on the small area such as a jaw becomes possible. The EMG electrode parameters are chosen as Fig. 3 (b) based on the commercial electrode (*delsys DE-2.1*) in order to measure the movement of *mentalis* and *submentalis* muscles located in the jaw during sleep. In Fig. 2, the block diagram of the integrated IC in SN patch is also presented. The bio-signals through the electrodes are amplified and digitized in the IC. And then, they are transmitted to the NC patch through network interface in order to collect, compress, locally process, and transfer them to the external station. The circuit layer is identical in all SN patches except the gain and bandwidth of the programmable gain and bandwidth amplifier (PGA) in the IC, which are fixed before use. The gain and bandwidth settings for each bio-signal are shown in Table I. All SN patches do not contain their own individual battery, but include the wire interface for power supply as will be described in session III. For stable power, not the wireless interface but the wired interface with the snap button is adopted. The power layer in SN patch has the role of power distribution to the whole ICs with the low resistance.

B. NC patch for Network Control

There is only one NC patch in the proposed system. The optimally designed IC in [7] is also integrated in the patch, and it can collect and locally process the data from all SN patches. Fig. 4 shows the structure of the NC patch. It consists of 4 layers; electrode, power, IC integration, and antenna for external communication.

The electrode in the NC patch is used as the reference electrode for ECG, EEG, and EOG signals. The suggested place for this electrode and the NC patch is behind the ear since there are no muscles but only the bones, which results in EMG noise suppression.

The data from all SN patches are collected in the NC patch. The dedicated IC, of which block diagram is also shown in Fig. 4, filters, compresses, and temporarily stores the data. After the internal memory is filled up, another IC in [8] sends the data to the external station as will be explained in session IV. For this type of data

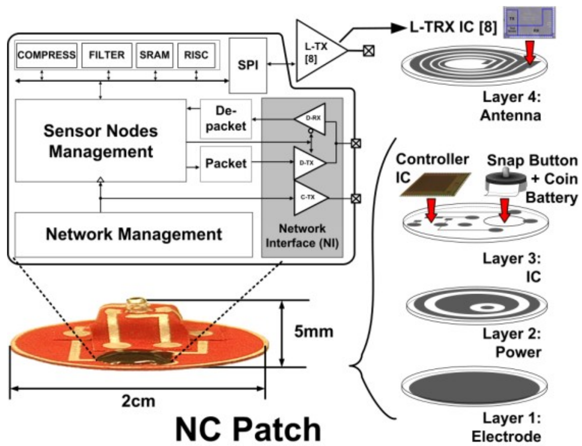

Fig. 4. NC patch for network control

transmission, the fabric inductor is integrated into the 4th layer as a near-field antenna. Since it is also printed on the fabric, it does not make any irritation to users.

The small coin battery is also integrated in the IC layer of the NC patch. The size of this battery is only 5.8mm in diameter and 2.1mm in thickness. And weight of the battery itself is about 2g, so the total weight of the system becomes less than 5g including 15 Smart Patches which is 0.2g and 0.3g per one SN and NC patch, respectively. And the power is transmitted from the NC patch to all SN patches using a snap button through W-Band in session III.

III. Wearable Band (W-Band)

In the proposed system, Wearable Band (W-Band) is developed in order to connect all Smart Patches. In the W-Band, there are 5 sub-lines for all different signal connections. For the correct operation, the power, ground, reference, data and clock lines should be connected with those of all patches. The data and clock lines are separated for low power synchronous 2-wire protocol implementation named Continuous Data Transmission (CDT) [7]. Since each of them should be electrically shielded in order to prevent electrical short, the coated conductive yarn and non-conductive fabric are adopted for each sub-line and W-Band, respectively.

Fig. 5 shows the structure of the W-Band. Several female snap buttons are placed on the W-Band, and transmission channels are located on them for 5 sub-lines.

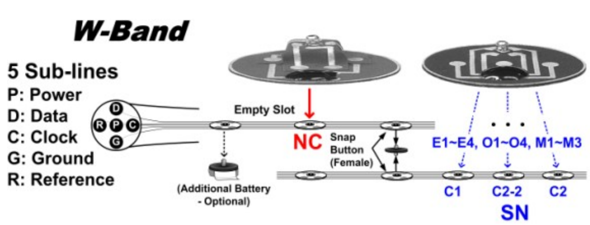

Fig. 5. Structure of W-Band

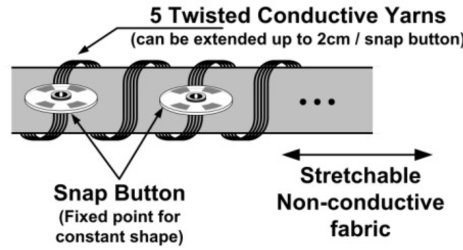

Fig. 6. Principle of stretchability in W-Band

At each female snap button, not only the NC and SN patches but also any components with male snap button such as an additional battery could be placed. Moreover, W-Band can be extended by using the male snap buttons in both sides so as to achieve more user convenience. Since the shape or size of the human face is different for each person, the distance between snap buttons should be varied according to either users or patch locations, which requires accurate data about the distances in advance of the use. Therefore, the stretchable type W-Band is proposed in this work as shown in Fig. 6. Basically, the snap buttons are placed at the same distance on W-Band. And if the user wants to increase the length, it can be just extended. Otherwise, it shrinks to the original length thanks to the elasticity of the non-conductive fabric which used as W-Band. Although the conductive yarn for each sub-line has no stretchability, it has the twisted shape so that the extra length of 2cm per snap button can be hidden.

The proposed system is operated as follows. First, all Smart Patches are attached on the proper locations of the human face. Then W-Band connects all patches starting from the NC patch. Once a patch is connected to W-Band, it is powered on so that it starts to operate. During sleep, bio-signals from the human body and face is monitored, recorded, and transmitted through corresponding Smart Patches. After the user wakes up, he or she can check the result through the display interface as will be shown in section IV.

IV. Data Display on Personal Devices

The data from all SN patches are collected in the NC patch. Although each SN patch has its own ID number, the collected data is not visible to the user. Therefore, the data is reformatted and visualized in the personal device such as PC, PDA or Smart phones. In the proposed system, it is implemented using *TI MSP-EXP430F5438 (MSP430 F5438 Experimenter board)*. Fig. 7 shows the signal flow in the proposed system. As described in previous sections II and III, the bio-signals are recorded by SN patches and collected in the NC patch through W-Band. And it is transmitted using an inductive coupling interface. In the *MSP-EXP430F5438*, the data

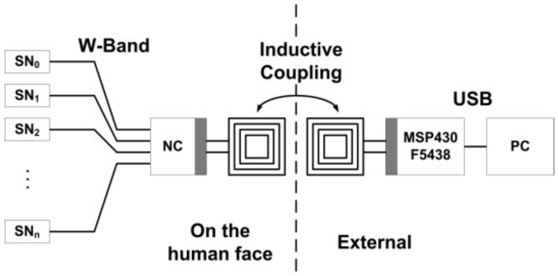

Fig. 7. Measured bio-signal flow

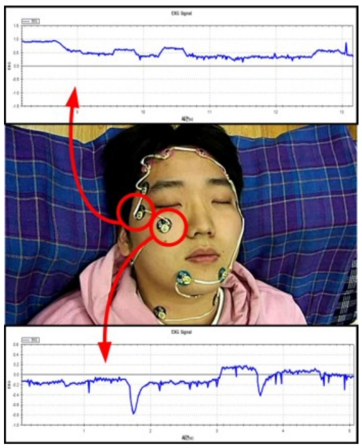
Fig. 8. Proposed system and its measurement result

Table II. System summary

Spec.	SN	NC
Size	2cm (D) = 310mm^2	2cm (D) = 310mm^2
Thickness	2mm	5mm
Weight	0.2g	0.3g
Power Cons.	25µW	75µW
Spec.	**System**	
Total Weight	< 5g	
Battery	Coin Battery (5.8mm (D) x 2.1mm (T), 2g)	
Life-time	> 42-h (@ 14mAh, 1.5V, 500µW)	
Board Type	P-FCB (Fabric)	
Application	Sleep Monitoring	

format is converted and displayed in the personal devices.

The system implementation is shown in Fig. 8. The proposed sleep monitoring system is attached to the user face, and during 8-hour sleep, the bio-signals of ECG, EEG, EMG, and EOG are recorded in the 20KB internal SRAM. And if it becomes full, the stored data is transmitted to the external device. The upper and lower graphs represent the recorded data from two SN patches, and they are displayed on the PC. The lower one is vertical EOG waveform, and the upper one is horizontal EOG waveform. Other signals (ECG, EMG, and EEG) are also recorded and separately displayed in the same way. The proposed system specification is summarized in Table II. Thanks to the low power Smart Patches and W-Band, it can operate over 42 hours using only one small battery. By using this proposed sleep monitoring system, convenient and comfortable measurement of bio-signals can be achieved. And this system is expected to be effectively utilized for recognition and diagnosis of several sleep disorders.

V. Conclusions

The very light-weighted and convenient sleep monitoring system is developed using the Smart Patches and Wearable Band (W-Band) with the help of Planar Fashionable Circuit Board (P-FCB) techniques. With the Smart Patches on the plain fabric, the total weight of the system including a battery is only less than 5g, which makes no irritation or hardness feeling for sleepers. Each patch integrates the dedicated IC so that it can serve either the bio-signal sensing or network control function. The wearable and stretchable W-Band is also proposed for convenient connection between Smart Patches with both low power consumption and low cost. The external data display interface shows that the bio-signals can be recorded well during sleep by the proposed system.

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