Patch Type Integrated Sensor System for Measuring Electrical and Mechanical Cardiac Activities

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***Abstract*— The ElectroMechanical Film (EMFi), a thin and flexible piezoelectric material, has been widely used as a mechanical sensor or actuator. Especially in Biomedical Engineering field, many researchers have used EMFi for measuring ballistocardiogram (BCG) which is a mechanical signal caused by blood ejection from heart. However, previous methods required special equipments installed on a chair or a bed to measure BCG. In this preliminary study, we designed a flexible patch type sensor that can measure electrical and mechanical signal simultaneously on a single unit. The Ballistocardiogram-Electrocardiogram patch (BEpatch), integrated with flexible circuit and attached to chest, can successfully measure fine electrocardiogram (ECG) and BCG signals simultaneously. The result shows that BEpatch can be used for continuous monitoring of bio-signals in a simple and comfortable manner, thereby, advantageous as a wearable health care device.**

Keywords— wearable sensor, EMFi, flexible patch type sensor, BCG, ECG

I. INTRODUCTION

EMFi is a quasi-piezoelectric material composed of homogeneous exterior surface layer and a number of interior polypropylene (PP) layers separated by air voids. When external forces or pressures are applied on the surface of the film, the thickness of the air voids will change causing movement of the charges residing on the PP / void interfaces and this generates charge to the external electrodes [1, 2]. With these electret properties, EMFi have been widely used as a mechanical sensor or actuator.

EMFi film has many advantages. EMFi film is thin (30 ~ 70μm) and air-voided giving flexibility. EMFi also has sensitivity to dynamic forces exerted normal to surface of the film (30 ~ 170 pC/N) [2]. Low-priced base material, PP, gives another advantage to EMFi. It is also easy to cut to various shape and size.

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A number of various applications have been developed and commercialized applying these advantages of EMFi film, such as, keyboard, speaker, floor sensor [3-5]. Especially, EMFi film provides biomedical engineers a new method for measuring BCG (measurement of the body's mechanical reaction to the blood flow [6, 7]). These methods embed EMFi film under chair [8, 9], bed [10], and scale [11] to measure BCG. In addition, ECG or Photoplethysmogram (PPG) is measured in parallel to obtain additional parameters, such as pulse arrival time (PAT) or R-J interval. Such parameters are used to estimate blood pressure [11-14], and nervous system [15, 16] respectively.

Despite the effort, the previous methods require separated unit of sensors to obtain each signals, and has limitations to be used in continuous monitoring due to the requirements of electrodes to be attached on beds or chairs.

In this paper, we propose a film based sensors that can simultaneous measure BCG and ECG on a single point of the body. In this, the metallized electrode layer of EMFi film was used not only to obtain a BCG, but also used to pick up electrical signal, ECG. Moreover, we took advantage of EMFi's flexible and easily modifiable characteristic to develop a patch-typed sensor, to make it attached on a chest of human body.

BEpatch (Ballistocardiogram-Electrocardiogram patch) can measure both ECG & BCG signals on a single point, giving comfortable experience to object without additional devices. Also, continuous and long-term measurement is possible because the sensor is attached directly to object's body without any inconvenience.

Also, by integrating BEpatch with flexible circuits, we suggested a possible approach using BEpatch as wearable health-care device. This device can detect important factors, such as blood pressure, based on previous researches, offering non-intrusive, continuous and comfortable monitoring.

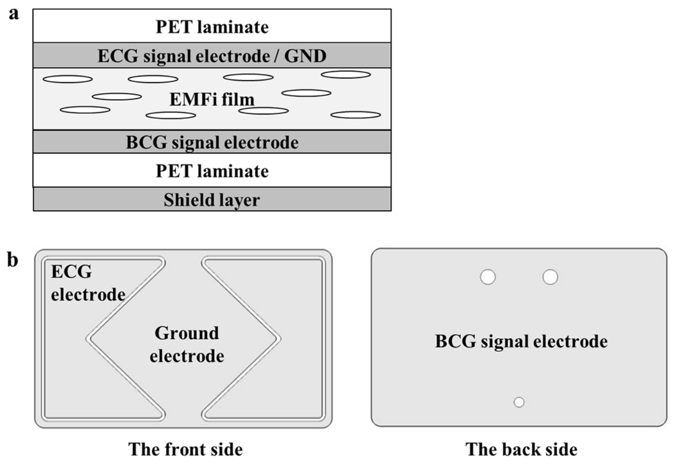

Fig. 1. a : Layer structure of the BEpatch. Emfi film was coverd with silver screened print both side. Then PET was laminated on mettalized surface. b : Design of both side of BEpatch.

II. SYSTEM DESCRIPTION

A. Layer structure of BEpatch

BEpatch was developed based on commercial Ferro-electret film (Emfit Ltd, FINLAND). BEpatch was constructed in multiple layers as shown in Fig. 1. a. At the middle of the layers, EMFi film takes place (thickness 90μm) and the top and bottom of EMFi film were covered with screen-printed silver electrode, and laminated with polyethylene terephthalate (PET). To decrease noise, a metal shielded layer was added below the PET layer of BCG signal electrode side.

B. Design of the electrodes

Considering conformal contact and ease of contact, the dimension of BEpatch was set to 9 cm x 5 cm. Also to increase the detection of signals, the shape of ECG electrode was designed in rhombus-shape as shown Fig. 1. b. At the front side of BEpatch, where BEpatch contacts with a chest, ECG electrode and ground electrode are screen-printed and laminated with PET. ECG electrode and ground electrode were separated by 1 mm gap of insulating EMFi film, and connected to a flexible circuit on the reverse side of BEpatch through holes. Around the holes, insulating gaps were given to prevent circuit shorted.

C. Circuit Integration

The circuit was integrated at the back-side of the BE patch to perform signal conditioning and wireless communication with PC for data transmission. The connection points between the circuit and the electrodes were made with via holes filled with silver paste around them. Signals were amplified and filtered using a TLC2274 (Texas Instrument, USA) operational amplifier. An MCU was used to digitize and to transmit the digitized signal to PC using a Bluetooth module. Fig. 2 shows the block diagram of the overall system. ECG was amplified by a hundred times by differential amplification through voltage follower, filtered by high-pass filter (fc = 0.16Hz) then filtered and amplified once more by active high-pass filter (amplified by 100 times, fc = 53Hz). BCG signal was amplified by 2000 times using a high-sensitivity current-voltage converter, and filtered with a Sallen-Key second order Butterworth low pass filter (fc = 40Hz), and a notch filter (60Hz), and then transmitted to MCU. ATmega128 (Texas Instrument, which state, USA) was used as MCU and sampling rate was 300Hz during A/D conversion. Fb155bc (FirmTech, Korea), Bluetooth module, was used for wireless communication with PC.

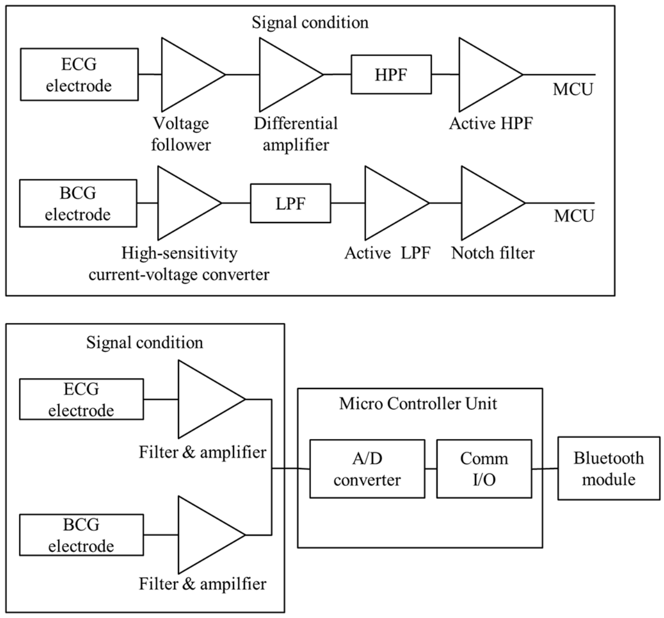

Fig. 2. Schematic diagram of the integrated flexible circuit. Circuit is devided into two parts, signal comdition module and digital module.

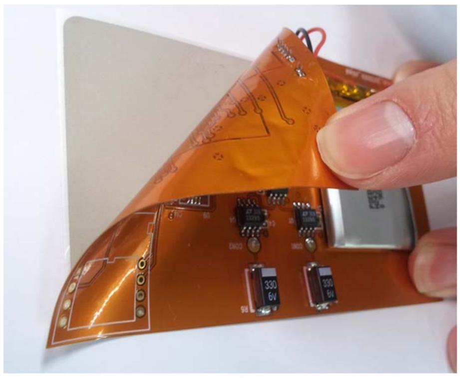

Fig. 3. Integrated system of BEpatch & flexible circuit. The flexibility of circuit enables the integration of circuit to BEpatch's flexibility.

III. SIGNAL VALIDATION

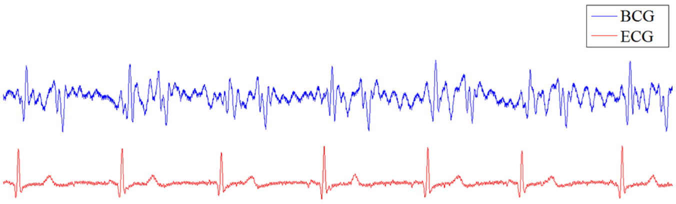

Fig. 4. BCG & ECG signals measured simultaneously from chest using BEpatch.

BEpatch was attached to the subject's chest to obtain ECG and BCG signal. In order to ensure conformal contact, the overall device was covered with a flexible, moisture permeable and waterproof film (OPSITE FLEXIFIX, Smith&Nephew, USA). Subjects were asked to refrain from moving during the measurement, since the BCG is susceptible to noise from movement.

Fig. 4 is a plot of the BCG and ECG measured simultaneously from BEpatch. The peak to peak voltage was around 1V, and the QRS complex of the ECG and J peak of the BCG were clearly confirmed. The result indicates that BEpatch can measure both ECG and BCG signal simultaneously from a single point. Only a few electrical elements were needed to obtain clear ECG signal. In case of BCG, even though patch was relatively small, clear signal was obtained. It is regarded that flexibility and conformal surface area of patch provides this result.

IV. CONSLUSION & DISCCUSION

Measurements using BEpatch showed appropriate signals of both ECG and BCG. It was identified that a simple filter can be used to obtain good ECG signals. Furthermore, despite the small size of the patch, the obtained BCG signals were clear. This result was due to the flexible electrode design that increased contact area when attached.

Wearing BEpatch did not cause any discomforts in daily activity. This is a major advantage of the patch in applications. Also, the patch is reusable and easily replaceable since the patch can be separated from the circuit so that only the patch can be replaced for continuous use. However, one of the limitations of the patch is the minimized movement of the test subject during the BCG measurements since BCG is sensitive to motion artifacts.

Because BEpatch can measure both electrical and mechanical signals on a single point, the sensor can be attached to various parts of the body besides the chest to measure different biological signals such as Electromyography (EMG) and muscular movement. Based on the current study of ECG and BCG, the patch can be applied to developing methods to measure various biological signals that are difficult to obtain, and it will be possible to conveniently and continuously detect such signals.

References

[1] J. Lekkala and M. Paajanen, "EMFi-New electret material for sensors and actuators," in Electrets, 1999. ISE 10. Proceedings. 10th International Symposium on, 1999, pp. 743-746.

[2] M. Paajanen, J. Lekkala, and K. Kirjavainen, "ElectroMechanical Film (EMFi)—a new multipurpose electret material," Sensors and Actuators A: Physical, vol. 84, pp. 95-102, 2000.

[3] M. Antila, H. Nykänen, and K. Saarinen, "Multichannel electromechanical film panel loudspeaker," in Audio Engineering Society Conference: 16th International Conference: Spatial Sound Reproduction, 1999.

[4] G. Buchberger, R. Schwodiauer, N. Arnold, and S. Bauer, "Cellular ferroelectrets for flexible touchpads, keyboards and tactile sensors," in Sensors, 2008 IEEE, 2008, pp. 1520-1523.

[5] J. Lekkala, R. Poramo, K. Nyholm, and T. Kaikkonen, "EMF force sensor-a flexible and sensitive electret film for physiological applications," Medical and Biological Engineering and Computing, vol. 34, pp. 67-68, 1996.

[6] R. S. GUBNER, M. RODSTEIN, and H. E. UNGERLEIDER, "Ballistocardiography An Appraisal of Technic, Physiologic Principles, and Clinical Value," Circulation, vol. 7, pp. 268-286, 1953.

[7] W. R. SCARBOROUGH and B. M. BAKER, "Editorial Ballistocardiography—Appraisal of Current Status," Circulation, vol. 16, pp. 971-975, 1957.

[8] S. Junnila, A. Akhbardeh, L. C. Barna, I. Defee, and A. Varri, "A wireless ballistocardiographic chair," in Engineering in Medicine and Biology Society, 2006. EMBS'06. 28th Annual International Conference of the IEEE, 2006, pp. 5932-5935.

[9] T. Koivistoinen, S. Junnila, A. Varri, and T. Koobi, "A new method for measuring the ballistocardiogram using EMFi sensors in a normal chair," in Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE, 2004, pp. 2026-2029.

[10] J. Alametsä, E. Rauhala, E. Huupponen, A. Saastamoinen, A. Värri, A. Joutsen, et al., "Automatic detection of spiking events in EMFi sheet during sleep," Medical engineering & physics, vol. 28, pp. 267-275, 2006.

[11] J. H. Shin, K. M. Lee, and K. S. Park, "Non-constrained monitoring of systolic blood pressure on a weighing scale," Physiological Measurement, vol. 30, p. 679, 2009.

[12] J. S. Kim, Y. J. Chee, J. W. Park, J. W. Choi, and K. S. Park, "A new approach for non-intrusive monitoring of blood pressure on a toilet seat," Physiological measurement, vol. 27, p. 203, 2006.

[13] J. M. Kortelainen and J. Virkkala, "FFT averaging of multichannel BCG signals from bed mattress sensor to improve estimation of heart beat interval," in Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE, 2007, pp. 6685-6688.

[14] E. Pinheiro, O. Postolache, and P. Girao, "Pulse arrival time and ballistocardiogram application to blood pressure variability estimation," in Medical Measurements and Applications, 2009. MeMeA 2009. IEEE International Workshop on, 2009, pp. 132-136.

[15] O. Postolache, P. Girão, and G. Postolache, "New approach on cardiac autonomic control estimation based on BCG processing," in Electrical and Computer Engineering, 2007. CCECE 2007. Canadian Conference on, 2007, pp. 876-879.

[16] O. Postolache, G. Postolache, and P. Girão, "New device for assessment of autonomous nervous system functioning in psychophysiology," in Medical Measurement and Applications, 2007. MEMEA'07. IEEE International Workshop on, 2007, pp. 1-5.