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The Compact Electro-Acupuncture System for Multi-Modal Feedback Electro-Acupuncture Treatment

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***Abstract*— The compact electro-acupuncture (EA) system is proposed for the multi-modal feedback EA treatment. It is composed of a needle, a smart patch, and an interconnecting conductive thread. The 3cm diameter compact EA patch is implemented with the EA controller integrated circuit (IC) and the small coin battery on the planar-fashionable circuit board (P-FCB) technology. It can achieve the user convenience and the low manufacturing cost at once by removing the wire connections. The EA controller IC programs the stimulation current and also monitors the electromyography (EMG) and the skin temperature during the EA stimulation. The measured data can be wirelessly transmitted to the external EA analyzer through the body channel communication with low power consumption. The external EA analyzer can check the patient's status, such as the muscle fatigue and the change of the skin temperature, and the practitioner can change the stimulation parameters for the optimal curative value. The proposed compact EA system is fully implemented and tested on the human body.**

I. Introduction

Acupuncture has been practiced in the oriental countries for thousands of years. Recently, it has been recognized in the western world and gradually accepted as a beneficial form of the complementary medicine [1, 2]. As a combination of the acupuncture and electrical current stimulation, the electro-acupuncture (EA) stimulation was demonstrated as effective for the pain relief in 1970s [3] and since then it has been widely used for the treatment of various diseases [4] such as depression, addiction, and gastrointestinal disorders and non-medical applications including obesity treatment [5]. To realize the EA stimulation, the conventional wired EA system uses a pair of thin needles (ϕ=0.2mm) which are connected to the external EA controller with thick and heavy wires for stimulating the human body. Unfortunately, the previous wired EA system suffers from two fatal problems:

1) *Inconvenience*: A slender wire-connected needle is easily bent or even pulled out by the patient's slight motion during the EA treatment. Consequently, the patient's mobility is severely limited, and it increases the stress or even brings dangerous side effects to the patient. Furthermore, the practitioner should continuously pay careful attention and check the wire connectivity for the stable EA treatment. Recently, the wirelessly-powered EA system in [6] was proposed to remove the cumbersome wire connections for the convenient treatment. However, its wireless harvesting power level is only 8μW, which is far too low to be applied in the various EA applications [1-5].

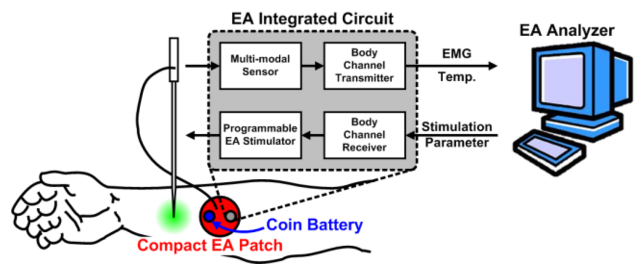

Figure 1. Proposed Electro-Acupuncture (EA) System.

2) *No-feedback*: During the previous EA treatment, the practitioner can monitor the patient only with the unaided eye so that they do not have any scientific feedback parameters to represent the patient's status. As a result, they have no choice but to empirically and subjectively determine the stimulation parameters, such as the stimulation time, amplitude, frequency and pulse width. Furthermore, the practitioner cannot even know whether the EA stimulation works or not.

In this paper, a new system for the multi-modal feedback EA treatment is proposed to solve the abovementioned problems at once. It consists of the compact EA patch on the human skin, and the external EA analyzer developed in the PC as shown in the Fig. 1. The compact EA patch realizes the EA stimulation without the cumbersome wire connections to the external EA analyzer so that it can achieve the user convenience. Besides, during the EA stimulation, the practitioner can check the patient's status through the proposed display interface with the multi-modal sensor in [7]. It shows the patient's status, such as the muscle fatigue and the change of the skin temperature, from the compact EA patch so that the practitioner can adaptively control the stimulation parameters to reflect the patient's status for the high remedial value.

The rest of this paper is organized as follows. In Section II, the compact EA patch for either the EA stimulation or the multi-modal sensing will be presented. The multi-modal feedback EA treatment between the EA patch and the external EA analyzer will be shown in Section III. Section IV presents the system summary results. Finally, the conclusions will be made in Section V.

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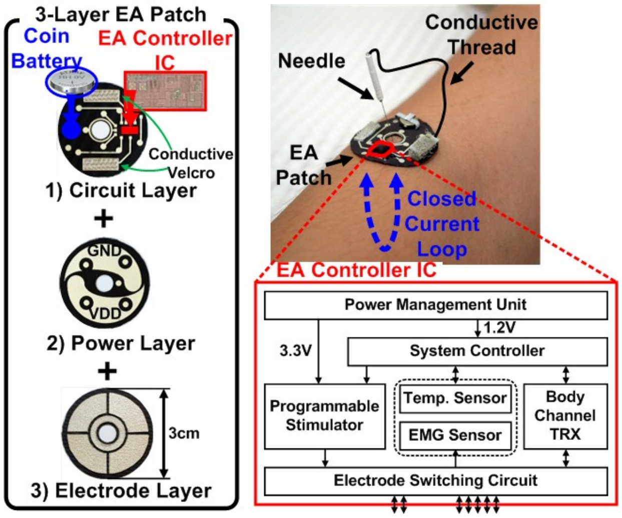


Figure 2. Compact EA Patch for Multi-Modal Feedback EA Treatment.

II. COMPACT ELECTRO-ACUPUNCTURE PATCH

The compact EA patch is implemented on the multi-layered fabric patch based on the planar-fashionable circuit board (P-FCB) technology [8, 9] as shown in the Fig. 2. The optimally designed EA controller IC in [7] is integrated on the compact EA patch so that it can monitor the patient's status and adaptively control the stimulation parameters during the EA treatment. The compact EA patch consists of 3 layers; 1) the circuit, 2) the power, and 3) the electrode layers. The coin battery, EA controller IC, and conductive velcro are implemented on the circuit layer. The small coin battery (diameter=6.8mm, height=2.15mm) provides an independent power (1.2V, 6.8mAh) to the EA controller IC so that it can remove the external wire connections for usability. The EA controller IC has five key building blocks for the multi-modal feedback EA treatment; 1) power management unit for the high stimulation voltage domain (3.3V), 2) system controller for the digital control, 3) programmable stimulator for the stimulation current injection, 4) multi-modal sensor for the electromyography (EMG) and the skin temperature recording, and 5) body channel transceiver for the external communication. The needle electrode is connected to the EA controller IC through the short and light conductive thread and

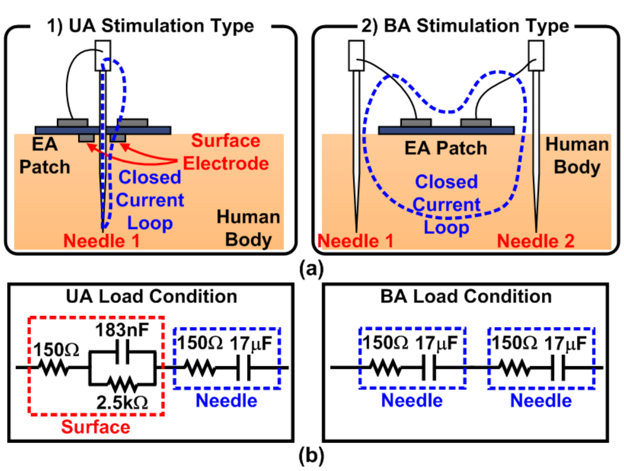


Figure 3. (a) Two Stimulation Types and (b) Load Conditions.

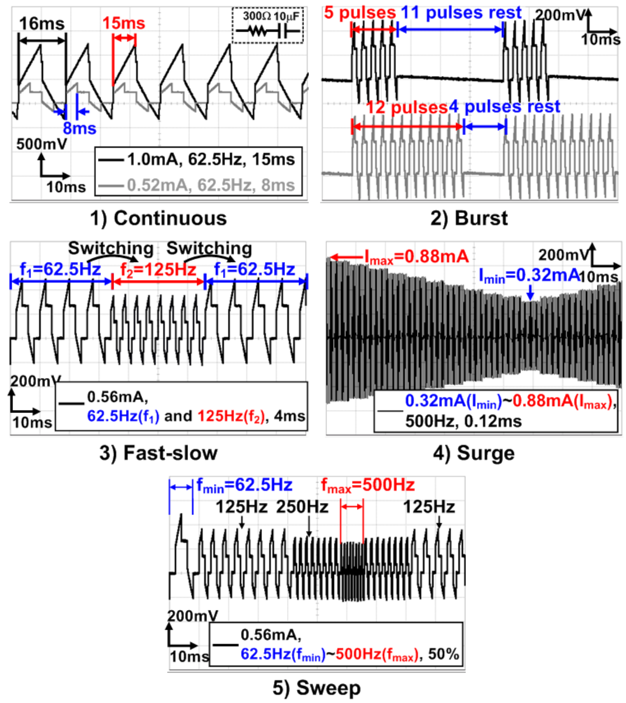


Figure 4. 5 Different Stimulation Modes.

Table 1. Stimulation Parameter Ranges.

Stim. Type	UA	BA
Amplitude	40μA ~ 0.32mA	40μA ~ 1mA
Frequency	0.5 ~ 500Hz	0.5 ~ 500Hz
Pulse Width	50μs ~ 0.94s	50μs ~ 0.94s

the conductive velcro on the patch for user convenience. The reconfigurable surface electrodes are printed on the electrode layer which diameter is 3cm.

The proposed compact EA patch provides 2 different stimulation types to form a closed current loop; 1) Uni-Acupoint (UA) stimulation, and 2) Bi-Acupoint (BA) stimulation as shown in the Fig. 3 (a). The UA stimulation type uses one needle electrode and surface electrodes as an anode and cathode in the EA stimulation, respectively, so that it can reduce the number of the required needles for the stimulation. It stimulates the human tissue around the single acupoint [10]. The BA stimulation type uses two needle electrodes and stimulates the human tissue between two acupoints. The load impedance conditions of the UA and BA types are shown in the Fig. 3 (b).

As shown in the Fig. 4, the compact EA patch provides 5 different stimulation modes which are used in a commercial EA system; 1) continuous mode with constant amplitude, frequency, and pulse width, 2) burst mode with periodic concentration and rest, 3) fast-slow mode with frequency alternation, 4) surge mode with amplitude sweeping, and 5) sweep mode with frequency sweeping. In each stimulation mode, the stimulation parameters can be programmable in the range as shown in the Table. I.

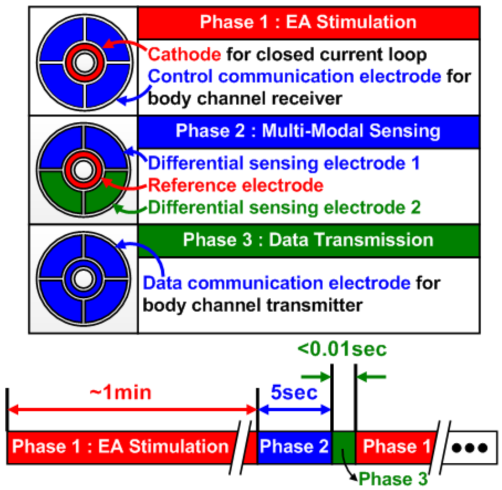


Figure 5. Reconfigurable Surface Electrodes for Multi-Modal Feedback EA Treatment.

III. MULTI-MODAL FEEDBACK EA TREATMENT

During the EA stimulation, the compact EA patch measures the EMG and the skin temperature signal from the human body and updates the stimulation parameters to reflect the patient's status with the help of the reconfigurable surface electrodes as shown in the Fig. 5. In the EA stimulation phase (phase 1), the surface electrodes are used as the cathode of the stimulation closed current loop, and also as the control signal communication electrodes to receive the stimulation parameters through the body channel communication [11]. Every minute, the multi-modal sensor in the EA controller IC measures the EMG and the skin temperature using the surface electrodes as differential sensing electrodes and the reference electrode for 5 seconds (phase 2). Inner circular electrode acts as a reference and the upper 2 electrodes and the lower 2 electrodes are differential electrodes. The EMG signal is recorded with the resolution of 8 bit/sample and the sampling rate of 2kHz. The skin temperature is also recorded in 6 bit resolution. The measured data is stored into the on-chip SRAM (10kB) in the EA controller IC. After that, the body channel transceiver [11] transmits the stored data to the external EA analyzer with low power consumption (1.6mW) and high data rate (1.25Mbps) through the all surface electrodes as data communication electrodes within 0.01 seconds (phase 3). The external EA analyzer extracts the patient's status, such as the muscle fatigue and the change of the skin temperature. Then, the practitioner checks the patient's status and properly updates the stimulation parameters. The updated control signals of the stimulation parameters are uploaded to the compact EA patch through the body channel.

In the proposed compact EA system, the external EA analyzer is implemented using the PC with the 1:N body channel communication interface [11] for the multi-channel EA treatment. In the proposed system, the communication interface is implemented using TI MSP-EXP430F5438 (MSP430 F5438 Experimental Board). Fig. 6 (a) shows the signal flow in the proposed compact EA system. The multi-modal signals are recorded during the EA stimulation in the compact EA patch. And then, it is transmitted using a body channel communication interface to the MSP-EXP430F5438 which converts the data format to the USB data. After the feature extraction processing, the PC GUI shows the patient's status, such as the muscle fatigue and the change of the skin temperature as shown in the Fig. 6 (b). In the proposed EA system, the median frequency (MF) method is used for the muscle fatigue extraction. The MF is defined as the frequency that divides the power spectrum into two of equal area. The low frequency shift of the MF can be interpreted as a sign of the local muscle fatigue [12]. After the practitioner checks the patient's status, the stimulation parameters are properly updated. And then, the updated stimulation parameters are transmitted to the compact EA patch.

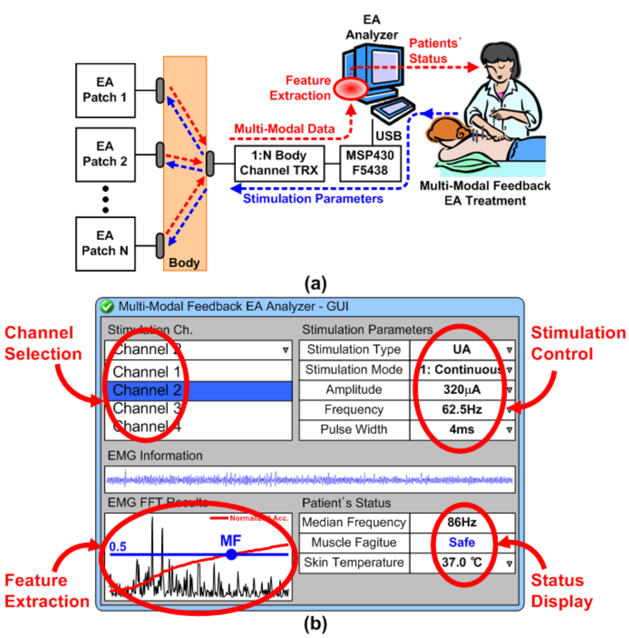


Figure 6. (a) Multi-Modal Feedback EA Signal Flow and (b) PC GUI.

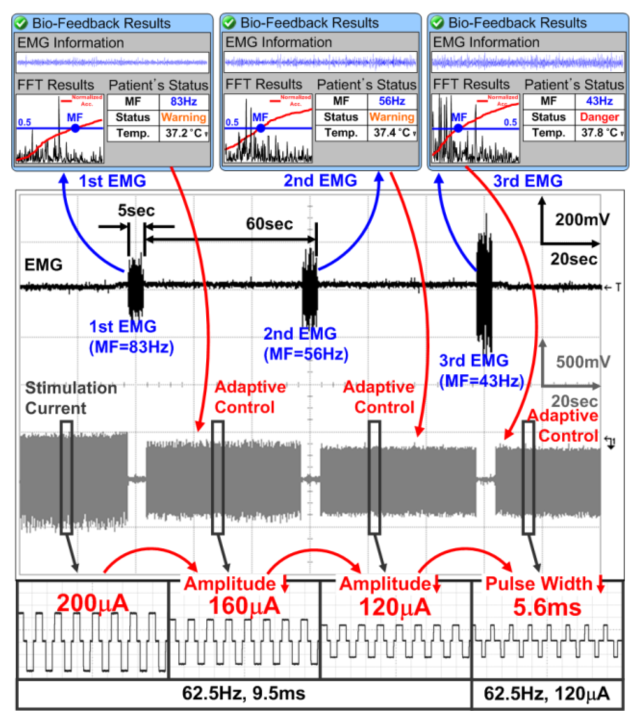


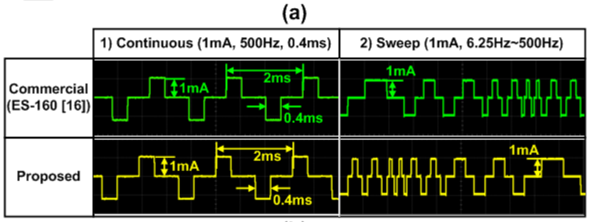
Figure 7. Example of Multi-Modal Feedback EA Treatment.

Fig. 7 shows the example of the multi-modal feedback EA treatment. The muscle fatigue is accumulated by repeated EA stimulations. Fig. 7 shows that the MF of the 3rd EMG is shifted to the low frequency (43Hz) from the MF of the 1st EMG (83Hz) due to the repeated EA stimulation. To avoid the accumulated muscular fatigue, the stimulation current amplitude and the pulse width is reduced from 200μA to 120μA and 9.4ms to 5.6ms, respectively.

IV. System Summary

		Nerve Stimulation [13]	Pain Relief [14]	Obesity [15]	This Work
# of Stim. Ch.		2	1	5	> 10
EA Time		30 min	20 min	30 min	1 hour
Stim. Parameter	Mode	2 modes	2 modes	1 mode	5 modes
	Intensity	0.36mA~0.5mA	0.1mA~0.2mA	-	40μA~1mA
		-	-	3V	3.3V
	Frequency	5Hz	200Hz	2Hz	0.5Hz~500Hz
	Pulse Width	0.5ms	0.1ms	50μs	50μs~0.94s

(a)



(b)

Figure 8. (a) System Summary with Various EA Applications and (b) Stimulation Current Verification with ES-160 [16].

The system summary results with various EA applications are shown in the Fig. 8 (a). The proposed compact EA system provides wide stimulation parameter ranges to cover the both medical and non-medical applications, such as nerve stimulation [13], pain relief [14], and obesity treatment [15]. Besides, it can remove the cumbersome wire connections and reduce the number of required needles per stimulation channel for user convenience. The optimal curative value also can be achieved by the multi-modal feedback EA treatment. The electrical characteristic of the proposed EA system is compared with the commercial EA system (ES-160) [16] for verification. As shown in the Fig. 8 (b), if the stimulation parameters of the proposed EA system and the ES-160 are equal, the output current waveforms are also equal. As a result, we can guarantee that the proposed EA system achieves the same stimulation effect of the commercial EA system.

V. Conclusion

A very convenient and effective electro-acupuncture (EA) system is developed using the compact EA patch with the planar-fashionable circuit board (P-FCB) techniques. For the user convenience, we remove the external wire connections and reduce the number of the required needles for the stimulation with the proposed compact EA patch. The compact EA patch integrates the dedicated controller integrated circuit (IC) so that it can measure the electromyography (EMG) and the skin temperature during the EA stimulation. The body channel communication is also used for the wireless communication between the EA patch and external EA analyzer with low power consumption. The external EA analyzer shows the patient's status, such as the muscle fatigue and the change of skin temperature, for the multi-modal feedback. Consequently, the practitioner checks the patient's status during the EA stimulation, and aptly updates the stimulation parameters for the safe and efficient EA treatment. Compared to the commercial EA system, the proposed EA system injects the same stimulation current and achieves the same stimulation effect in the various EA applications. As a result, this system is expected to be effectively utilized for the optimal and interactive acupuncture with the real-time multi-modal feedback signals and programmable stimulation as well as safe and convenient EA treatment.

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