Self-powered electro-tactile system for virtual tactile experiences

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Abstract—Tactile sensation plays important roles in virtual reality (VR) and augmented reality (AR) systems. Here, a self-powered, painless and highly sensitive electro-tactile (ET) system for achieving virtual tactile experiences is proposed based on triboelectric nanogenerator (TENG) and ET interface formed of ball-shaped electrode array. Electrostatic discharge triggered by TENG can induce notable ET stimulation, while controlled distance between the ET electrodes and human skin can regulate the induced discharge current. The ion-bombardment technique has been used to enhance the electrification capability of triboelectric polymer. This TENG-based ET system can work for many fields, including virtual tactile displays, braille instruction, intelligent protective suits or even nerve stimulation.

I. INTRODUCTION

Currently, there exists two major approaches for realizing artificial tactile sense, via mechanical or electrical stimulation. Mechano-tactile devices can achieve safe and highly controllable stimulations for VR/AR sensation[1,2], but are always fabricated with complex structures and needs relatively high-power consumptions[3]. Alternatively, electro-tactile (ET) devices are advantageous due to its small size, light weight and high resolution[4]. Nevertheless, the human epidermis has rather large resistances, which makes it quite challenging to decide an appropriate voltage for creating desired stimulations without pain[5].

Herein, we propose a self-powered and skin-integrated ET system for realizing enhanced virtual tactile experiences. The high output voltage and low output current of triboelectric nanogenerator (TENG) can provide notable non-contact electrostimulation to skin, indicating a different approach for the field of virtual tactile sensations. By controlling the separation distance between electrode and human skin, this TENG-based ET system can precisely regulate the induced current on skin and a highly sensitive but painless virtual tactile experience is achieved. For perspective, this self-powered ET system can be integrated on spacesuit or positive-pressure protective suite to offer users a sensation of virtual physical contact with outside. The proposed ET system will provide a new direction of TENG’s application and extend self-powered virtual tactile stimulations to medical and aerospace fields.

II. RESULTS

A. Enhanced virtual tactile experiences enabled by TENG

Fig. 1A depicts the working principle and operation process of this proposed ET system. The touching and sliding motion on TENGs can be directly transferred into electrostatic signals, while these signals are conducted to the ET interface integrated on human skin. Each ball-shaped electrode on the ET interface is connected with the specific TENG unit in the TENG array and the signal provided by TENG unit can induced electrostatic discharge from the ball-shaped electrode to skin. Finally, the virtual tactile stimulations with specific patterns are reproduced on skin through these electric stimulations. Fig. 1B presents the disassemble structure of the ET interface as well as electrode array, where 21 ball-shaped electrodes are encapsulated in a wearable band. The tiny balls made of tin are set of 0.5 mm in diameter and the distance between two adjacent electrodes is 15 mm. All the tin balls are conglutinated to copper (Cu) electrodes on one side of polyethylene terephthalate (PET), which forms the discharging electrodes, and wires are arranged on the other side through prepared aperture. Both sides are packaged by dielectric polytetrafluoroethylene (PTFE). Finally, a VHB tape with designed thickness is applied to cover the ET interface, creating an adhesive surface for attaching on the skin. Fig. 1C gives the discharging process of ET system, where the TENG array of sliding mode is used to provide driving power. A series of tiny holes are pouched on the VHB tape by laser drilling and the ball-shaped electrodes can induce discharge signal through these holes (see Fig. 1C). The optical microscope image of this electrode array is shown in Fig. 1D with an insert microscopic view of a ball-shaped electrode and the optical imagine of TENG is displayed in Fig. 1E. The TENG array consists of a PTFE film (negative tribolayer) covering an array of back electrode (Cu), and a freestanding acrylic substrate covered by ion bombarded Kapton (IB-Kapton). The induced IB-Kapton with enhanced electrification capability can improve the performance of TENG, Thus the TENG with the contact area of 4 cm² is capable of triggering discharge, leading to a compact system.

978-1-6654-6968-5/22/$31.00 ©2022 IEEE
Fig. 1  Skin-integrated electro-tactile interface. (A) The schematic illustration of ET system to transmit virtual spatial pattern. (B) The exploded-view of the electrode array. (C) The electro-tactile sense of ET system. (D) Optical images of the electrode array. The insert shows an enlarge view of a ball electrode. (E) Image of the TENG array.

B. On-skin ET interface and the tactile sensation

Fig. 2 summarizes a possible application of this ET system as a virtual interaction technique, where TENG can serve a bridge for the people at different places to experience virtual tactile communications. As shown in Fig. 2A, the ET interface is attached on the forearm of a girl, whose eyes are covered. Based on the ET stimulation induced by TENG, the girl is capable of giving right feedbacks when random numbers are written on the surface of TENG, as can be seen in Fig. 2B. As this ET system is able to transfer virtual signals into tactile sensations through ET stimulus, it is expected to combine auditor and visual stimuli to establish complete VR systems for enhancing tactile experiences during non-contact communications, such as an isolation ward or prison visiting.

C. Integrated ET system for augmented tactile sensations.

An integrated ET system based on contact-separation TENG is designed to enhance tactile sensations for applying where people’s tactile sensation is weakened or blocked, such as wearing armor, protective suits or even space suits. With these protective suits, human tactile sensations of surrounding environments are strongly weakened and accordingly, the potential damage to protective suit happened in the blind area of the user may not be easily and timely noticed. By applying this kind of ET system, it is possible to achieve an intelligent protective suit, where the users can obtain a more sensitive interaction with surrounding environment. Moreover, this TENG-based ET system has the advantage of simple structure, low cost and zero-power consumption, showing great applicability with different protective suits. Hence, this self-powered ET system can be integrated on various locations (shaded in Fig. 5F (I) and (II)) and provide a series of information about contact or hurt to the user through enhanced tactile sensation.

Fig. 3 An integrated ET system. (A, B and C) The structure of an ET unit (A), optical image of the system fabricated in semicylinder (B) and illustration when integrated on forearm (C). (D and E) the discharging current (D) and transferred charges (E) of ET system unit. (F) The schematic diagram of positive-pressure protective suit (I) and spacesuit (II) equipped with ET system (the shaded location) respectively.

III. CONCLUSIONS

A skin integrated ET system has been proposed with the help of TENG technique, which can provide harmless, sensitive and zero-power virtual tactile experiences. The high voltage of TENG assisted with the non-contacted ET interface can trigger non-contact electrostatic discharge as stimulation and induce harmless electro tactile sensations. An on-skin ET matrix with 21 stimulating points is fabricated to demonstrate the virtual tactile sensation, where both the touching position and the motion trace on a remote TENG array can be precisely reproduced on human skin trough ET stimulus. A wearable and wireless ET system can provide augmented tactile sensations for establishing real-time virtual contact with physical world. Hence, this self-powered ET system can promote the application of tactile VR/AR in many fields, including but not limited in tactile prosthetics, Braille instruction, intelligent protective suits and so on.

ACKNOWLEDGMENT

This work was supported by the National Key R&D Project from Minister of Science and Technology (2016YFA0202704), the National Natural Science Foundation of China (Grant No. 51775049) and Beijing Natural Science Foundation (4192069).

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