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Research Highlight

Mechanoluminescence-powered bite-controlled human–machine interface

Chunfeng Wang [a,b], Hongjie Hu [c], Deliang Zhu [a], Caofeng Pan [b,d,*]

[a] College of Materials Science and Engineering, Guangdong Research Center for Interfacial Engineering of Functional Materials, Shenzhen University, Shenzhen 518060, China
[b] CAS Center for Excellence in Nanoscience, Beijing Key Laboratory of Micro-nano Energy and Sensor, Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, Beijing 100083, China
[c] Materials Science and Engineering Program, University of California San Diego, La Jolla, CA 92093, USA
[d] School of Nanoscience and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

Human–machine interfaces (HMIs) enable the intuitive cognition and interaction between users and devices [1–3]. The conventional HMIs such as mouse, keyboard and touchscreen have significantly simplified the manipulations of computers and associated devices, while they suffer from bulk, big footprint and mechanical noncompliance for applications in virtual/augmented reality and Internet of Things, and more importantly, difficulties in operation for people with disabilities such as dexterity impairments or neurological conditions [4,5]. Accordingly, novel HMIs exploiting biosignals including voice, electromyogram (EMG), electroencephalogram (EEG) and electrooculogram (EOG) have been developed for hand-free control [6,7], however, challenges remain for their practical applications, such as noise interference for voice recognition, invasiveness and discomfort for brain-machine interfaces. Occlusion is an interactive process of mandible and maxillary teeth, bones, and muscles in dental context, and the force during the process can be defined as bite force. Compared to voice, EMG, EEG, and EOG, the recognition of dental occlusion patterns for HMIs presents the merits of anti-interference, noninvasiveness, convenience, comfort, safety, and easy control. And analysis of the bite force can give quantified information on occlusion patterns, which provides an additional control for interaction. Thus, the detection of dental occlusion holds great promise for the realization of hand-free and non-invasive HMIs. This requires a soft pressure sensing device to convert occlusion information into inputs for application implementations.

Soft pressure sensors based on different mechanisms including piezoelectric, piezoresistive, capacitive, triboelectric, and optic have currently been developed, among which soft optical pressure sensor, especially, soft distributed-optical-fiber (DOF) sensor characterized by spatially resolved and time-dependent measurements, is ideal for the construction of the proposed interactive device [8]. However, an external light source is necessary for the DOF sensor, complexing the device fabrication and general usage. Mechanoluminescence (ML) is a phenomenon that lights can be directly generated by mechanical stimuli. With the attributes of high brightness (>300 cd/m^2), multicolor (UV–vis-NIR), stability (>10,0000 cycles), and energy-autonomy, ML materials have been emerging in a myriad of areas such as sensing, illumination, and bioimaging [9]. The integration of ML materials and DOF is therefore a promising solution to the aforementioned issue.

Recently, Prof. Xiaogang Liu and colleagues demonstrated an interactive mouthguard capable of recognizing the patterns of dental occlusion and translating them into commands to enable disabled people to control devices like computers, smartphones and wheelchairs with high accuracy [10]. The first-of-its-kind mouthguard is composed of an array of mechanoluminescence-powered distributed-optical-fiber (mp-DOF) sensors, a flexible printed circuit board and a flexible polyethylene terephthalate substrate, as shown in Fig. 1a. The DOF sensor is powered by mechanoluminescent ZnS:M to convert bite forces into heterochromatic lights in an energy-autonomous manner. The mp-DOF sensors with optimized structure, dimension and component exhibit a linear response to force at the range of 5–60 N with a sensitivity of 20 counts per newton and have good stability upon dynamic and repeated compressions, endowing the effective and robust record of bite patterns. A 2 × 3 single-layer mp-DOF sensor array with six predetermined mechanoluminescent pads can detect 21 bite patterns in theory, 14 of which are processed for bite-controlled operation after considering the adaptive comfort of the users. In this progress, the mechanoluminescent signals upon biting travel along with the fiber to the color sensor chips to generate the CIE spectral tristimulus values of X, Y and Z, which are then converted into CIE xyY color space for the precise distinction of bite patterns (Fig. 1b). The distinction has a high accuracy of >98%, assisted by a trained two-layer, feedforward artificial neural network (ANN). Meanwhile, the system possesses robustness and consistency to varied biting positions and participants. The occlusion patterns can be easily translated into instructions to control electronic gadgets after pairing with a Bluetooth module, as illustrated in Fig. 1c. The implementations of making phone calls, controlling a wheelchair and playing a virtual piano were demonstrated in a remote, rapid and hand-free way. Moreover,

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* Corresponding author.
E-mail address: cfpan@binn.cas.cn (C. Pan).

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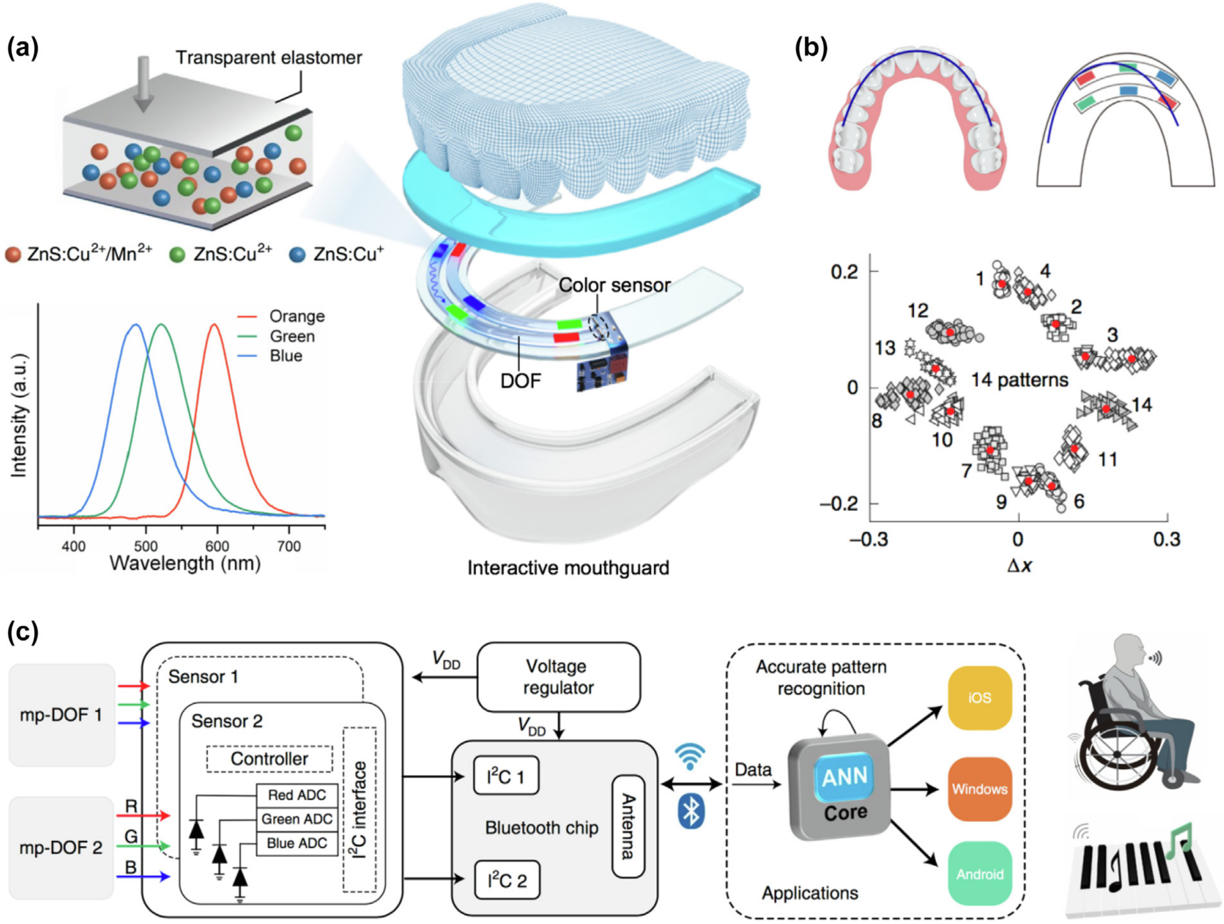

Fig. 1. (Color online) Mechanoluminescence-powered bite-controlled human–machine interface. (a) Schematic of the interactive mouthguard with an array of distributed-optical-fiber (DOF) sensors. Each sensor contains differently colored mechanoluminescent materials of ZnS:M, which can convert bite forces into heterochromatic lights in an energy-autonomous manner. (b) Detection and distinction of bite patterns assisted with machine learning algorithms. (c) Flow chart of interactive mouthguard control. Copyright © 2022, Springer Nature.

the associated information of occlusion patterns such as luminance intensity can be utilized for the additional interactive manipulation, benefiting from the proportional dependence of mechanoluminescence intensity on the magnitude of bite force. The interaction has an average accuracy of around 95% for participants with different tooth shapes and occlusal habits, demonstrating the efficacy of this approach.

Challenges remain about this achievement could be the comfort, biosafety, lifetime, and cost. Muscle fatigue or even inflammation could happen if the mouthguard is not comfortable for long-term wear. The biosafety of ZnS:M should be concerned for their use in mouth, and long service life of the device should be guaranteed. The total cost of the prototype sits at around 100 Singaporean dollars (about US $70) now, although it is expected that a mass-produced commercial version would cost much less. Moreover, aesthetic and invisibility should also be considered for this device design and all the other interactive electronics.

In summary, a new scheme has been proposed for the dexterous interaction between users and devices with the fashion of free-of-hand, non-invasiveness, terseness, energy-efficiency and high precision. This new scheme holds great promise to promote independence and autonomy for people with severe disabilities.

Conflict of interest

The authors declare that they have no conflict of interest.

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Chunfeng Wang received his B.S. degree in Materials Science and Engineering from Zhengzhou University in 2013, and his Ph.D. degree in Materials Processing Engineering from Zhengzhou University in 2019. He is currently an assistant professor at College of Materials Science and Engineering, Shenzhen University. His research interest includes optoelectronic materials and soft devices.

Caofeng Pan received his B.S. (2005) and his Ph.D. (2010) degrees in Materials Science and Engineering from Tsinghua University, China. He then joined the Georgia Institute of Technology as a postdoctoral fellow. He is currently a professor and has been a group leader at Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences since 2013. His main research interest focuses on the fields of low-dimensional materials for fabricating smart electronic and optoelectronic devices for tactile sensing.