An Artificial Neural Tactile Sensing System

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Humans detect tactile stimuli through a combination of pressure and vibration signals using different types of cutaneous receptor. However, construting systems mimicking and containing mechanoreceptors has not been achieved yet. Therefore, we developed an artificial neural tactile skin system that mimics the human tactile recognition process using particle-based polymer composite sensors and a signal-converting system. The sensors respond to pressure and vibration selectively, similarly to slow adaptive and fast adaptive mechanoreceptors in human skin, and can generate sensory neuron-like output signal patterns. We showed the undistorted transmission of the signals through an mouse nerve fibre is possible, and the artificial finger containing sensor can learn to classify fine and complex textures with a deep learning technique. The developed human-like systems would be applied in robotics and prosthetics to provide real tactile sensation in e-skin.

1. Background (objectives)

Human tactile perception is a complex process related to the detection of pressure and vibration in spatiotemporal mechanical deformations on glabrous skin. In particular, human skin perceives tactile stimuli through cutaneous mechanoreceptors in which slow adaptive (SA) and fast adaptive (FA) receptors respond sensitively and selectively to static pressure and vibration (high-frequency dynamic pressure).

While various strategies have been developed to mimic each receptor type, there have only been a few demonstrations of sensors that can achieve both functions simultaneously. Moreover, the development of practical tactile perception systems will also require sensors that are human compatible (thin, lightweight, adhesive and deformable) and economical (cheap and mass producible using a simple fabrication process).

Recent approaches have shown that tactile recognition systems can be mimicked by creating artificial mechanoreceptors and afferent nerves, and by integration of these components with bioinspired approaches. However, previously used simple approaches have only been based on intervals (SA) or on/off only (FA). This is in contrast with biological processes, where humans perceive tactile sensations on the basis of specific discharge patterns, which depend on the specific shape and roughness of the surface or object.

2. Contents

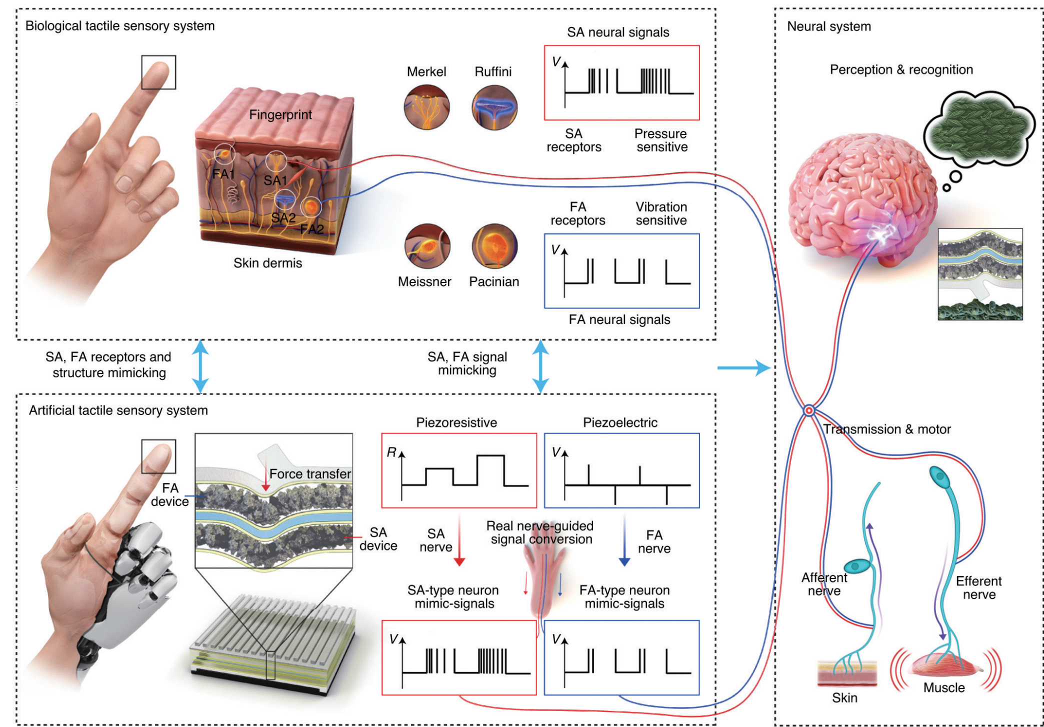
In the research, we have reported a bioinspired artificial neural tactile system (t-skin). The tactile skin device was fabricated by incorporating SA-mimicking rGO sheets and FA-mimicking $BaTiO_3$ nanoparticles in a polymeric PDMS matrix, providing sensors that are simultaneously sensitive to pressure and vibration.

Also, We designed a system which simultaneously modulates the SA and FA sensor outputs into neuron-mimicking signals separately. The signal conversion mechanism is based on the recorded response patterns of mouse nerves ex vivo to pressure and vibration stimuli to the hindpaw. The data we used in the conversion process are based on the mathematical function that uses the interspike interval (ISI) of firing activity of single A-beta fibres. After single-fibre recording and type-differentiation process, we produced a model equation reflecting the ISI by force (or pressure) level. With developed system, it is proved that conversed signals can be fully transmitted in real nerves or can generate the synaptic transmission required to trigger muscle contraction. In addition, the artificial finger consisting of t-skin system could learn and classify the fine and complex textures with a deep learning technique, as well as predict unknown texture on the basis of learned textures.

3. Expected effect

In the future, the developed artificial tactile sensing system could be integrated with existing or newly developed robotic/prosthetic systems to replicate the human sense of touch. This could significantly improve their performance on tasks that involve touching, grasping and manipulating objects. Moreover, the signal converting mechanism in the research could be used to synthesize the information of real sense of touch, which will be utilized in the field of metaverse and telecommunication. Lastly, the idea using biomimetic signal could be applied to develop the artifical organs to restore of other sense (sight, hearing, taste, smell, etc.) for the disabled people.

Figure.
Artificial tactile sensory system mimicking a biological system



Research outcomes

Paper S. Chun et al. An artificial neural tactile sensing system. Nat. Electron. 4:429-438 (2021)

S. Park et al.Adaptive and multifunctional hydrogel hybrid probes for long-term sensing and modulation of neural activity. Nat. Commun. 12:1-12 (2021)

Research funding

This study was supported by the Basic Science Research Program through the National Research Foundation of Korea (2020R1C1C1007589) a Korea Medical Device Development Fund grant funded by Ministry of Science and ICT, Ministry of Trade, Industry and Energy, Ministry of Health & Welfare, Ministry of Food and Drug Safety (NTIS no. 9991006805), the National R&D Program through the National Research Foundation of Korea funded by the Ministry of Science and ICT (2021M3H4A1A03048648 and 2021M3F3A2A01037365), the Smart Project Program through the KAIST-Khalifa Joint Research Center (KK-JRC), the KAIST College of Engineering Global Initiative Convergence Research Program, and the KAIST Post-AI Research Project.