GIST develops 'smart material' that distinguishes contact and flexibility like human skin… Realizing tactile embodied soft robots

- Professor Minjeong Ha's team at the Department of Materials Science and Engineering distinguishes the direction of complex forces, such as contact and bending, in real time using magnetic field-aligned nanowire-based materials... Separating tactile information without multiple sensors or computations

- Realization of a sensory-actuating integrated soft robot structure... Demonstration of autonomous hazardous substance isolation tasks

- Published in the international journal ***Advanced Materials***

▲ (From left) Yubin Kim, PhD student in the Department of Materials Science and Engineering at GIST, and Professor Minjeong Ha

The Gwangju Institute of Science and Technology (GIST, President Kichul Lim) announced that a research team led by Professor Minjeong Ha of the Department of Materials Science and Engineering has developed a technology capable of distinguishing complex forces by direction using the material itself, and has realized a "Perception-Embodied Soft Robot" by applying this technology.

This robot is characterized by its implementation of a "closed-loop feedback" function that distinguishes the direction of complex forces occurring simultaneously, such as contact (pressure) and bending (deformation), in real time without the need for various types of sensors or complex data processing. Based on this tactile information, the robot autonomously controls its next movement.

The research achievement is expected to be utilized in the future for applications such as: ▴ robots for exploring enclosed and irregular environments; ▴ smart electronic prosthetic arms and legs; ▴ remote haptic interfaces; and ▴ next-generation wearable robots.

For soft robots that can bend and deform freely like humans to precisely handle objects of various shapes, tactile capabilities capable of distinguishing between different mechanical stimuli, such as contact and bending, just like human skin, are essential.

However, existing tactile sensors had a crosstalk problem in which signals generated when joints bend and signals generated when external objects come into contact became mixed.

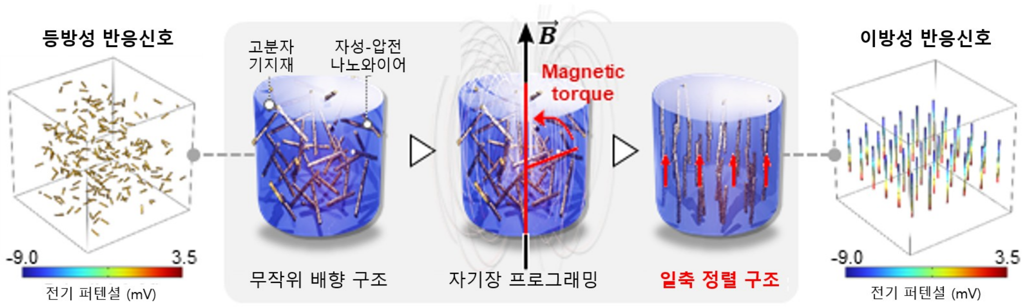
To solve this, it was necessary to densely arrange various types of sensors or separate signals through complex data calculations; however, this process reduced the robot's flexibility and degrees of freedom of movement, and also imposed limitations on real-time control.

To overcome these limitations, the research team developed a technology that uses magnetic fields to align nanowires along a desired axis and enables them to respond selectively to different forces depending on that direction.

To achieve this, the team utilized "nanowires," which are rod-shaped nano-sized materials much thinner than a human hair. Thanks to their thin and elongated structure, nanowires have the characteristic of reacting sensitively to concentrated external mechanical stimuli.

The "barium titanate ($BaTiO_3$) nanowires" used by the research team possess piezoelectric properties that generate electrical signals when subjected to force or pressure, allowing them to detect externally applied forces.

They fabricated "magnetic-piezoelectric nanowires" by coating the surface with iron oxide (Fe_3O_4) nanoparticles that respond to magnetic fields. Next, these were evenly dispersed in a shape-memory polymer** and aligned in the desired direction using an external magnetic field.



▲ *Directional control of a magnetic-piezoelectric composite material using a magnetic field. Magnetic-piezoelectric nanowires randomly dispersed within the polymer align along a specific axis upon receiving the force of an external magnetic field; through this, the material acquires a directionality that distinguishes the direction of the force.*

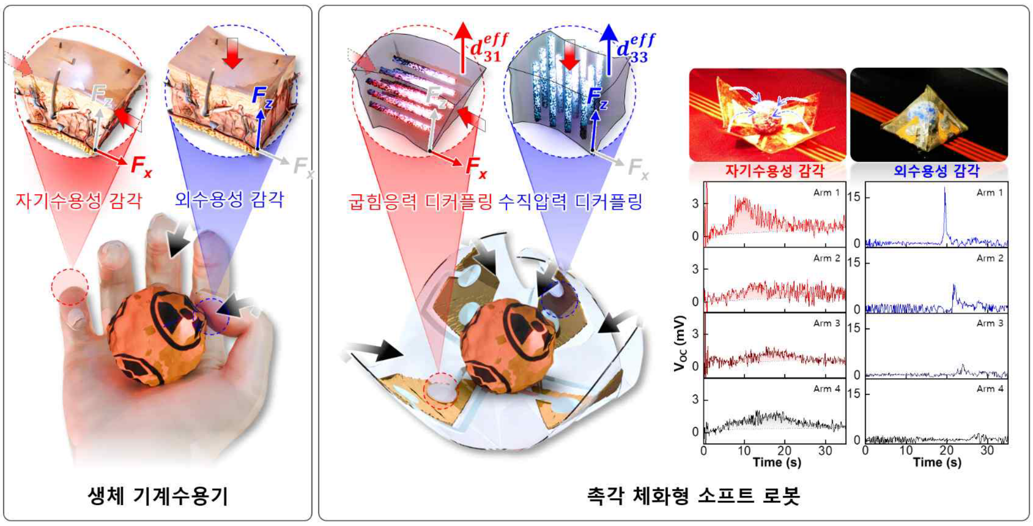
These aligned nanowires are fixed within the polymer to maintain their alignment direction and are designed to respond selectively only to forces applied from a specific direction.

> ** magnetic-piezoelectric nanowire: A composite material in which iron oxide nanoparticles that respond to magnetic fields are coated onto piezoelectric nanowires that convert mechanical force into electrical signals.*
>
> *** shape-memory polymer: A polymer with the characteristic of returning to its original shape upon receiving external stimuli such as heat; in this study, it serves to fix the nanowires and maintain their aligned direction.*

Nanowire structures aligned along the vertical (z-axis) direction responded sensitively to "vertical pressure" caused by external contact, while structures aligned along the horizontal (x-axis) direction responded selectively to "bending force" generated when joints bend.

In other words, the researchers confirmed that contact and bending signals can be physically separated (decoupled*) using only the aligned nanowire structures, without the need for separate use of various types of sensors or complex computations to separate signals.

> ** decoupling: Distinguishing between forces applied in multiple directions; in this study, this is achieved solely through the alignment structure of the material, without the need for multiple sensors or computations.*



▲ ***Operating principle of the "tactile embodied soft robot." Nanowires aligned by a magnetic field recognize joint movements and external contact separately without complex computations, and based on this, the robot controls its movements autonomously.***

Furthermore, the research team succeeded in distinguishing the direction of complex three-dimensional forces acting simultaneously along the x, y, and z axes by arranging nanowires aligned in different directions at right angles. This implements a 'sensory-actuated integrated structure' in which the robot body itself detects force and moves, rather than the conventional method of assembling sensory and actuating components separately.

The research team fabricated a 'tactile embodied soft robot' applying this technology and had it perform actual autonomous missions.

The robot operated by distinguishing between its own bending signals generated during the self-folding process and contact signals generated when touching an object, and based on this, it successfully performed the task of isolating hazardous chemicals.

▲ *Demonstration of autonomous hazardous substance isolation by a 'tactile embodied soft robot.' The robot autonomously deforms its structure to isolate hazardous substances (ammonia-based compounds) and demonstrates a 'closed-loop control' process in which it controls its movements by receiving real-time feedback on tactile contact signals.*

In particular, this process demonstrates the feasibility of realizing next-generation autonomous soft robots by relying solely on tactile information embedded within the robot, rather than depending on external cameras or complex computational systems.

Professor Ha Min-jeong stated, "This research is significant because, unlike existing robot sensory systems that relied on various sensors and large-scale computation, the material itself was designed to distinguish complex forces." She added, "It operates stably even under repetitive deformation and can recognize tactile sensations with high accuracy even in environments where visual information is difficult to obtain, so we expect it to contribute to the advancement of real-time autonomous robot control technology."

This research, supervised by Professor Minjeong Ha of the Department of Materials Science and Engineering at GIST and with doctoral student Yubin Kim as the first author, was supported by the Global Young Connect program of the Ministry of Science and ICT and the National Research Foundation of Korea.

The research results — Field-Programmed Anisotropy in Magneto-Piezoelectric Composites for Material-Encoded Mechanoperception — were published online on July 18, 2026, in the international materials science journal *Advanced Materials*.

Meanwhile, GIST stated that this research achievement takes into account both its academic significance and potential for industrial application, and that discussions regarding technology transfer can be conducted through the Technology Commercialization Center (hgmoon@gist.ac.kr).