Newborn baby inspires sensor design that simulates human touch

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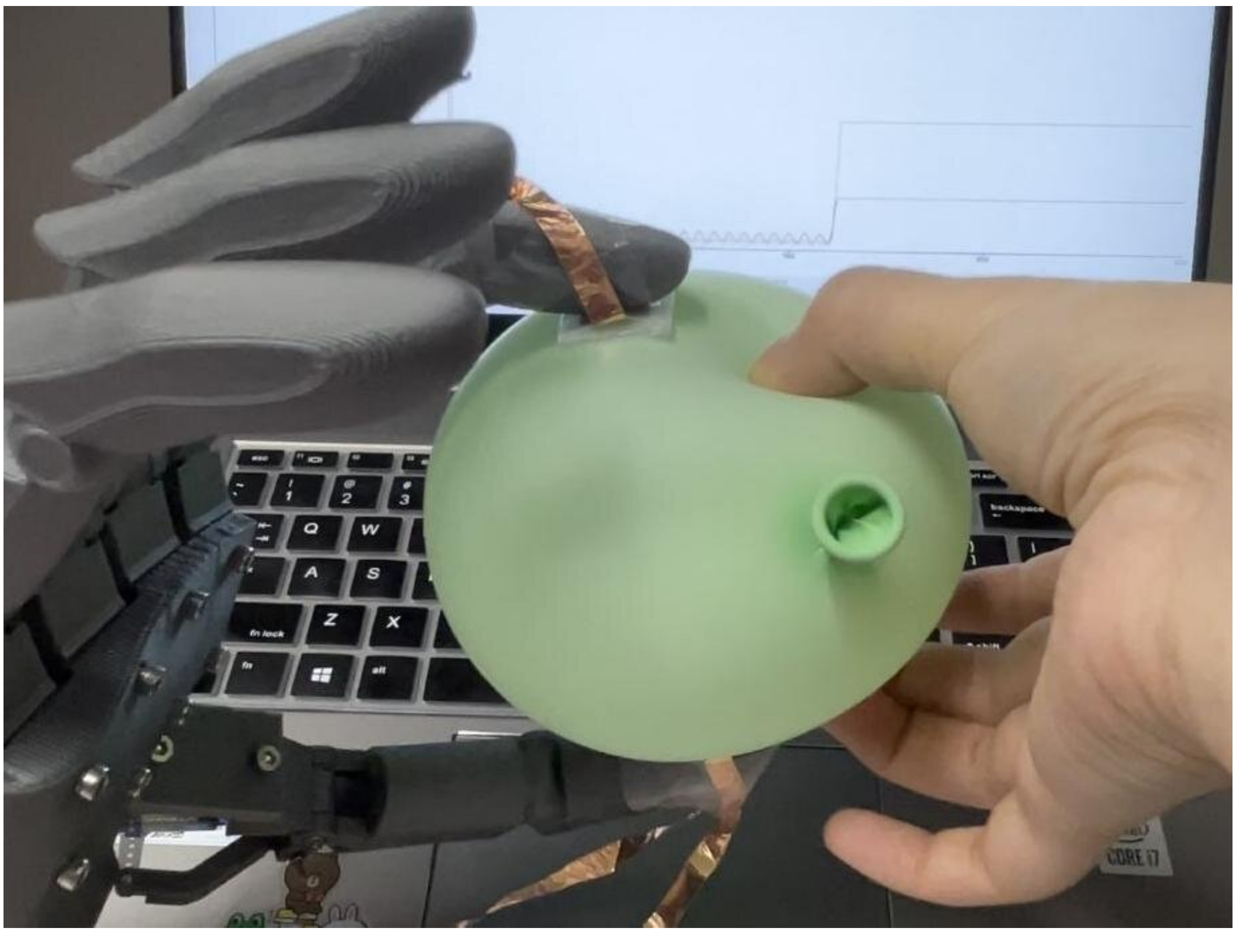

Testing the iontronic sensor's ability of tactile sensing via a robotic hand and a balloon. Credit: Cheng Group

As we move into a world where human-machine interactions are becoming more prominent, pressure sensors that are able to analyze and simulate human touch are likely to grow in demand.

One challenge facing engineers is the difficulty in making the kind of cost-effective, highly sensitive sensor necessary for applications such as detecting subtle pulses, operating robotic limbs, and creating ultrahigh-resolution scales. However, a team of researchers has developed a sensor capable of performing all of those tasks.

The researchers, from Penn State and Hebei University of Technology in China, wanted to create a sensor that was extremely sensitive and reliably linear over a broad range of applications, had high pressure resolution, and was able to work under large pressure preloads.

"The sensor can detect a tiny pressure when large pressure is already applied," said Huanyu "Larry" Cheng, James L. Henderson Jr. Memorial Associate Professor of Engineering Science and Mechanics at Penn State and co-author of a paper on the work published in *Nature Communications*.

"An analogy I like to use is it's like detecting a fly on top of an elephant. It can measure the slightest change in pressure, just like our skin does with touch."

Cheng was inspired to develop these sensors due to a very personal experience: The birth of his second daughter.

Cheng's daughter lost 10% of her body weight soon after birth, so the doctor asked him to weigh the baby every two days to monitor any additional loss or weight gain. Cheng tried to do this by weighing himself on a regular home weight scale and then weighing himself holding his daughter to measure the baby's weight.

"I noticed that when I put down my daughter in her blanket, when I was no longer holding her, you didn't see the change in weight," Cheng said. "So, we learned that trying to use a commercial scale doesn't work, it didn't detect the change in pressure."

After trying many different approaches, they found that using a pressure sensor consisting of gradient micro-pyramidal structures and an ultrathin ionic layer to give a capacitive response was the most promising.

However, there was a continued issue they faced. The high sensitivity of the microstructures would decrease as the pressure increased, and the random microstructures that were templated from natural objects resulted in uncontrollable deformation and a narrow linear range. In simple terms, when pressure was applied to the sensor, it would change the sensor's shape and therefore alter the contact area between the microstructures and throw off the readings.

To address these challenges, the scientists designed microstructure patterns that could increase the linear range without decreasing the sensitivity—they essentially made it flexible, so it could still function in the gradience of pressures that exist in the real world. Their study explored the use of a CO_2 laser with a Gaussian beam to fabricate programmable structures such as gradient pyramidal microstructures (GPM) for iontronic sensors, which are soft electronics that can mimic the perception functions of human skin.

This process reduces the cost and process complexity compared with photolithography, the method commonly used to prepare delicate microstructure patterns for sensors.

Cheng credits Ruoxi Yang, a graduate student in his lab and first author of the study, as the driver of this solution.

"Yang is a very smart student who introduced the idea to solve this sensor issue, which is really something like a combination of many small pieces, smartly engineered together," Cheng said.

"We know the structure must be microscale and must have a delicate design. But it is challenging to design or optimize the structure, and she worked with the laser system we have in our lab to make this possible. She has been working very hard in the past few years and was able to explore all these different parameters and be able to quickly screen throughout this parameter space to find and improve the performance."

This optimized sensor had rapid response and recovery times and excellent repeatability, which the team tested by detecting subtle pulses, operating interactive robotic hands, and creating ultrahigh-resolution, smart weight scales and chairs.

The scientists also found that the proposed fabrication approaches and design toolkit from this work could be leveraged to easily tune the pressure sensor performance for varying target applications and open opportunities to create other iontronic sensors, the range of sensors that use ionic liquids such as an ultrathin ionic layer. Along with enabling a future scale where it would be easier for parents to weigh their baby, these sensors would have other uses as well.

"We were also able to detect not only the pulse from the wrist but also from the other distal vascular structures like the eyebrow and the fingertip," Cheng said. "In addition, we combine that with the control system to show that this is possible to use for the future of human robotic interactional collaboration. Also, we envision other healthcare uses, such as someone who has lost a limb and this sensor could be part of a system to help them control a robotic limb."

Cheng noted other potential uses, such as sensors to measure a person's pulse during high-stress work situations such as search-and-rescue after an earthquake or carrying out difficult, dangerous tasks in a construction site.

The research team used computer simulations and computer-aided design to help them explore ideas for these novel sensors, which Cheng notes is challenging work given all the possible sensor solutions. This electronic assistance will continue to push the research forward.

"I think in the future it is possible to further improve the model and be able to account for more complex systems and then we can certainly understand how to make even better sensors," Cheng said.

More information: Ruoxi Yang et al, Iontronic pressure sensor with high sensitivity over ultra-broad linear range enabled by laser-induced gradient micro-pyramids, *Nature Communications* (2023). DOI: 10.1038/s41467-023-38274-2 , www.nature.com/articles/s41467-023-38274-2

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