Team develops fingertip sensitivity for robots

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In a paper published on February 23, 2022 in *Nature Machine Intelligence*, a team of scientists at the Max Planck Institute for Intelligent Systems (MPI-IS) introduce a robust soft haptic sensor named "Insight" that uses computer vision and a deep neural network to accurately estimate where objects come into contact with the sensor and

how large the applied forces are. The research project is a significant step toward robots being able to feel their environment as accurately as humans and animals. Like its natural counterpart, the fingertip sensor is very sensitive, robust, and high-resolution.

The thumb-shaped sensor is made of a soft shell built around a lightweight stiff skeleton. This skeleton holds up the structure much like bones stabilize the soft finger tissue. The shell is made from an elastomer mixed with dark but reflective aluminum flakes, resulting in an opaque grayish color that prevents any external light finding its way in. Hidden inside this finger-sized cap is a tiny 160-degree fish-eye camera, which records colorful images, illuminated by a ring of LEDs.

When any objects touch the sensor's shell, the appearance of the color pattern inside the sensor changes. The camera records images many times per second and feeds a deep neural network with this data. The algorithm detects even the smallest change in light in each pixel. Within a fraction of a second, the trained machine-learning model can map out where exactly the finger is contacting an object, determine how strong the forces are, and indicate the force direction. The model infers what scientists call a force map: It provides a force vector for every point in the three-dimensional fingertip.

"We achieved this excellent sensing performance through the innovative mechanical design of the shell, the tailored imaging system inside, automatic data collection, and cutting-edge deep learning," says Georg Martius, Max Planck Research Group Leader at MPI-IS, where he heads the Autonomous Learning Group. His Ph.D. student Huanbo Sun adds, "Our unique hybrid structure of a soft shell enclosing a stiff skeleton ensures high sensitivity and robustness. Our camera can detect even the slightest deformations of the surface from one single image." Indeed, while testing the sensor, the researchers realized it was sensitive enough to feel its own orientation relative to gravity.

The third member of the team is Katherine J. Kuchenbecker, Director of the Haptic Intelligence Department at MPI-IS. She confirms that the new sensor will be useful. "Previous soft haptic sensors had only small sensing areas, were delicate and difficult to make, and often could not feel forces parallel to the skin, which are essential for robotic manipulation like holding a glass of water or sliding a coin along a table," says Kuchenbecker.

But how does such a sensor learn? Huanbo Sun designed a testbed to generate the training data needed for the machine-learning model to understand the correlation between the change in raw image pixels and the forces applied. The testbed probed the sensor all around its surface and recorded the true contact force vector together with the camera image inside the sensor. In this way, about 200,000 measurements were generated. It took nearly three weeks to collect the data and another day to train the machine-learning model. Surviving this long experiment with so many different contact forces helped prove the robustness of Insight's mechanical design, and tests with a larger probe showed how well the sensing system generalizes.

Another special feature of the thumb-shaped sensor is that it possesses a nail-shaped zone with a thinner elastomer layer. This tactile fovea is designed to detect even tiny forces and detailed object shapes. For this super-sensitive zone, the scientists choose an elastomer thickness of 1.2 mm rather than the 4 mm they used on the rest of the finger sensor.

"The hardware and software design we present in our work can be transferred to a wide variety of robot parts with different shapes and precision requirements. The machine-learning architecture, training, and inference process are all general and can be applied to many other sensor designs," Huanbo Sun concludes.

 More information: Huanbo Sun et al, A soft thumb-sized vision-based

sensor with accurate all-round force perception, *Nature Machine Intelligence* (2022).

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