The World of Tactile Sensation

Clarifying the Mechanism of Tactile Sense from an Engineering Approach

A newly born child becomes aware of his own existence through tactile sensations. Skilled artisans and masseurs can acknowledge the most minute undulations at a level that is far beyond the capacity of a normal sensory receptive organ. Tactile sensation is so basic that our knowledge of its functions remain unknown. Much remains to be learned, particularly in the area of reproducing and applying tactile sensations.

Virtual Reality and Tactile Sense
Playing with a Virtual Cat

Could you please squat down for a while?

Squatting as I was told, I looked up at the car that appeared in front of me. The blue color of the car seat and its wooden frame made it look like a vehicle in an amusement park. But it did not appear frivolous. The car felt weighty, emitting a sense of tension.

You can stick your head into the drivers seat and look inside. The interior surely looks spacious, professor.

This is the essential interaction with virtual reality (VR). You do not enter commands or click the mouse to give instructions to the computer. All you need to do is move your body as you normally would be in actual space. If you peek inside, your action will generate the corresponding image.

We were experiencing the CABIN system developed and located at the Hongo Campus of Tokyo University. The room was covered with several screens, for the front side, for the two sides of the wall, the ceiling and floor. The three dimensional image is projected from five projectors.

The viewer who wears a magnetic sensor can view three dimensional images that are projected to match the view point of the person in accordance with the movement of the viewer's body and face. Professor Hirose Michitaka, an author of numerous VR related books, introduced us to this cabin. The authenticity of virtual reality is determined by the consistent linkage between the physical sensation and the image. We had requested to see the cabin to understand how tactile sense is projected.

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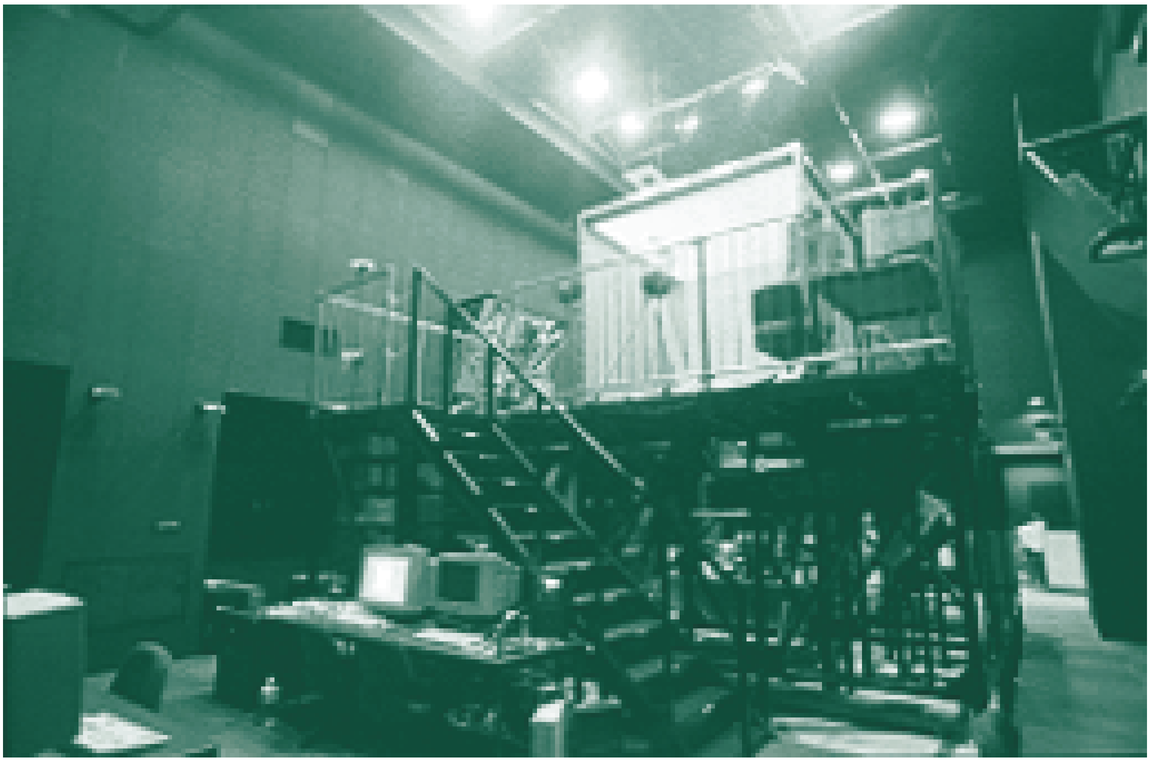
In a VR system such as this one, we have made breakthroughs in emulating vision. As a next step, it is only natural that we wish to experience tactile sense. This is because we want to touch something to believe that it is real.

We only confirm whether something is real or not by touching it. That is why synthesizing the tactile sense in electronic media is a fundamental theme for VR. Let me show you an example. Though the system is still not available yet, it is a Don Quixote like trial.

■ Demonstration 1 Feeling with the Whole Body

We walked through a virtual city wearing a suit that contains 12 oscillators. (See photo.) When we touch a road sign, the corresponding oscillator vibrates.

All of the basic elements of VR are consistent with the features of tactile sense. For example, it is interactive. Vision and hearing tend to be more or less passive, and that is why we can sit in front of a TV and receive information passively. But if tactile sense were passive it would be meaningless. Tactile sense can only be felt by movement, such as when we move our hands. In this system, before a person can receive tactile sense information, his movements must be detected and entered into a computer first. It is interactive from the start.



Cabin (Immersive Multiscreen Display)
The virtual space can appear in the white room at the center.

■ Demonstration 2. Touching with the Tip of a Pen

When we were guided into a separate room, there was a tactile sensing display which looked like a dental operating machine. When a liquid crystal shutter eyeglass is put on, the cat in the display turns into a three dimensional image. On the tip of the tactile sensing display is a pen which you can pick up to move closer to the cat. (See photo.) At a certain point you will feel some resistance. You have touched the body of the cat. Using the red pointer, you can trace the cat's body with the pen, and sense the bones and muscles of the cat. If you push the pen too hard, the cat will screech at you in anger. If you tickle the throat of the cat, the cat will purr happily.

With heightened awareness of tactile sensations, and if the display is limited to a very narrow space, it is possible to integrate vision with touch at a very minute level.

■ Demonstration 3. Wearing a Pen

You must carry a rucksack on your back and carry a pen-shaped equipment that is connected to the rucksack in front.

When you reach a virtual object, the thread that connects the pen with the rucksack will be pulled and the pen will be pressed against you. You will then feel the resistance.

When the focus of the body sensation is limited to a particular part of the body, even in a spacious area such as the cabin, it is possible to experience tactile sensations that are similar to system used for the virtual cat.

Direction of Tactile Display
Lessons from Birds and Airplanes

When the tactile organ is focused a particular part of the body, it is called a special sense. All other sensory systems except for the tactile are focused on only one part of the body. That is why it is easy to synthesize sensations. In the extreme, if signals are fed intensively through the eyes or nose, it is possible to fool our vision or sense of smell. However unlike other sensory organs, tactile sense is dispersed throughout the body. The scale of tactile sense is varied, ranging from the entire body to the texture felt by the fingertip. That is why a multifaceted approach is required. The operation principle for the tactile display differs totally from other types of systems.

The pen type was developed by applying robot arm technology. There are various types of pen systems which have oscillating pins that are lined up like a mountain of needles that vibrate vertically to display the dimension. Also a bodysuit which you can wear is an advanced version of the former.

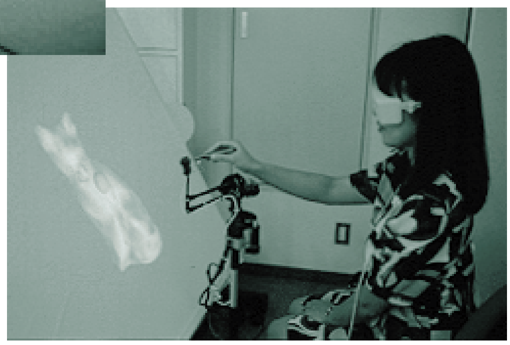
I believe that many new tactile sensing technology will be developed. Unlike the virtual vision systems which are all a variation of either the HMD (head mounting display) or the 360 degrees ceiling display, there are a whole range of possible mechanisms for developing virtual tactile sense. That is the interesting aspect of this technology. My approach is to focus on an interesting tactile sense that we have identified from the various situations created within the cabin, and integrate it with vision.

As tactile reproduction technology advances, physiological and anatomical observations will begin to play a significant role, says Professor Hirose. Also tactile displays will provide a new research methodology for physiology. As a result, as with the visual RGB, the development of tactile sensors will contribute to our understanding of tactile mechanisms.

But since tactile sense is dispersed all over the body, even though the mecha-

■ **Demonstration 1.**
Feeling with the Whole Body
By touching the road sign, the oscillator in the suit begins to vibrate. Professor Hirose hopes to eventually exchange three dimensional information of human beings between a similar facility in Tsukuba. “There was an old movie of an electronically transmitted person. It's that image I am thinking about.” What will it feel like when they can touch each other virtually....

■ **Demonstration 2.**
Touching with the Tip of a Pen
Touching a cat with a pen formed sensing display. Robot technology provided the basis for this mechanism. When a virtual object is touched, the robot arm becomes fixed, and the pen will not proceed any further. If the arm can be moved slightly by pressing the pen stronger, the hardness of the virtual object can also be expressed.



nism is clarified, will it really be possible to engineer applications?

Before the Wright Brothers developed the first airplane, flying machines emulated the shape and the flying mechanism of birds. Eventually people began to understand that the ability to balance lifting power and air resistance was what made birds fly. As a result, airplanes with simpler wings were developed. For tactile sense, if a feature is clarified, in developing applications that require that feature, a very accurate display can be developed. Just as airplanes now fly faster than birds, an electronic tactile sense that is even more real than the actual sense can be developed. Currently, the development of such a system is focused on accurately imitating the actual tactile sense. On the other hand, an approach which focuses on a particular feature and then extrapolates is required. The same applies to VR.

An Example of the Sensitivity Measurement and Production

A New Glove which Feels as Familiar as an Old One

Mr. Ochiai visited a Mizuno plant to order a new bat for the next season after he had won the triple crown in professional baseball. Mr. Ochiai picked up a sample bat and immediately complained that the grip was a bit too fat. When the grip was measured, it was 1 millimeter thicker than the bat Mr. Ochiai was using.

This episodes illustrates the polished intuition of a first rate professional baseball player. I heard this episode from Mr. Hisanobu Funabashi, deputy manager of the Sports Equipment Planning and Manufacturing Department, Mizuno Sports Business Division. In the world of sports, computers are widely used to develop shoes for top athletes. According to Mr. Funabashi, however, more than 90% of the baseball bats, gloves and other equipment are handmade because of high dependence on the skills and intuition of the workers. Baseball players too are extremely sensitive to the quality of a baseball glove.

When you continue catching balls during practice, a pocket appears on the glove naturally. The glove can only be used in a real game when an ideal pocket appears. Back in the old days in the US, it took one or two years of hard practice before a new glove would be used in a game. Gloves that have been sufficiently worked through to be used in a game cannot be used in practiced anymore. The glove is stored in the locker so that it will not deform.

The intuitive sensation of a skilled baseball glove worker and of the baseball athlete. There seems to be little room left for a computer to play a role. But in fact a huge opportunity exists here.

We asked about 200 professional baseball players in the US and Japan and with their cooperation we were able to obtain 3D data on the gloves used for games. A computer analysis of the data showed that the shape of the pocket differed according to the position of the player. And so we created a glove pattern based on this data.

The glove produced in this manner proved to be exceedingly popular among both the Japanese and American players who expressed satisfaction at the good fit of the new glove and the natural feel when they caught a ball. The share of Mizuno gloves jumped from 19% to 26% in American Major League baseball.

According to Mr. Funabashi, “some athletes are now saying that they would like to use Mizuno gloves even if they have to terminate their contracts with other manufacturers.”

A Novel Tactile Sensor
Softly Sandwiched

At birth, a baby cries first, and then becomes aware of his existence when he begins sucking on his mother's nipples. He sucks milk to live, and that feeling on his lip is the evidence that his lips are a part of himself. He learns to suck his thumb and understands that it is also a part of himself. By touching others, he becomes aware of the outer world and learns to see. (His tactile sense leads him into the world of vision.)

When I asked Professor Shimojo whether it was correct to say that most people are not as aware of their tactile sense as they are of vision, he said "yes, that's true but it is one of our most basic sense" and reiterated the experience of a baby.

In l981, Professor Shimojo was developing a pressure sensor to measure the comfort level of a bed at the Product Science Research Laboratory (currently Life Engineering Industry Technology Research Laboratory). Being interested in robots, Professor Shimojo was happy to be researching pressure = tactile sense.

At the laboratory you are obligated to research a special theme in addition to your selected theme. I had to study human motion detection. In this research, a light emitting diode is attached to the human hand, and its location is observed by using the PSD (semiconducting optical position detector). A colleague at that time, Mr. Masatoshi Ishikawa (currently assistant professor of Tokyo University) and myself were interested in the PSD and studied it. We discovered that on the silicon board an interesting structure appeared. This provided the hint for developing a new sensor for detecting tactile sensations, an area we were already researching.

The figure below gives a simple explanation of the PSD principle. When light is reflected onto the PSD, the electric current moves towards the electrodes on both sides. Depending on where the light was reflected, there is a potential difference between the two electrodes which is used to determine the position. Professor Shimojo and Professor Ishikawa saw the potential for applying this principle to tactile sense, and a special rubber came to mind.

Yokohama Rubber company had developed a pressure sensing dialectic rubber product. In the sponge-like silicon rubber, fine carbon particles which are dielectric are uniformly dispersed. When the rubber is pressed, since it is like a sponge, it shrinks. The dispersed carbon particles have to density, and the electric resistance is reduced. This is the mechanism.

This rubber is being used in electrical organs to vary sound according to the strength of the pressure applied to make it closer to a real piano.

Mr. Shimojo and Mr. Ishikawa developed a structure in which this pressure sensitive dielectric rubber is sandwiched in between two flat resistors. (See figure.) When a load is placed on a part, the electric resistance of the rubber changes, and the electric current flows from the top of the sandwich structure to the bottom. The potential difference between the two electrodes of the top plane is shown as the X coordinate. The potential difference between the two electrodes of the bottom plane is expressed as the Y-coordinate. In this manner it is possible to measure the amount of load and which area of the sensor the load was applied. This tactile sensor is unique because it is 0.7 millimeters thick (the minimum thickness available is 0.35 millimeters thick) and is soft. Focusing on these benefits, this structure was first wound around a robot's finger, and tested at Stanford University.

This technology is expected to be applied to ID authentication, because by signing the top of this sensor, the handwriting, writing sequence, and writing pressure can be converted into electrical codes.

Words describing tactile sensation

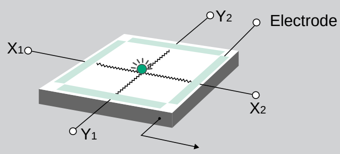
Words that describe tactile sense	warm, cold, hard, soft
Words that describe vision	bright, dark, red, blue
Words that describe auditory sense	noisy, silent, high, low

Words that describe tactile sense can also be used to describe other types of senses as well, some examples being a warm color, hard noise, soft sound, but words to describe vision or other senses cannot be used to describe tactile sense. You do not say that a texture is bright, or the hardness is quiet. As we develop, our concept of the world is first formed by our tactile sense, and then extrapolated to other senses.

■The concept of a thin and flexible tactile sensor

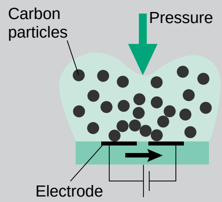
The hint was taken from an unlikely source (research of vision)
<PSD: Position Sensitive Detector>

When light is reflected, the electric current flows. The potential difference arises from the distance to the two electrodes. Therefore positioning information can be obtained.



Based on the unique material
<pressure sensitive dielectric rubber>

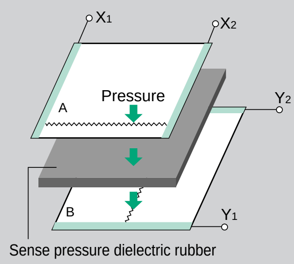
When pressed, the carbon particle which is dielectric adheres and the current flows.



Tactile sensor application
<sandwich structure>

The stronger the pressure, the faster will the electric current flow from plane A to plane B. Therefore, the level of the pressure can be analyzed.

If the potential difference between the electrodes is measured for both planes A and B, the pressure point can be analyzed.



The Mechanism for Increasing Sensitivity
Why People Can Pick Up Objects with Their Fingers

Researchers have only focused on the shape of hands and fingers in their efforts to clarify how human beings can grasp objects. The research has more or less ignored pressure or force as a factor because conventional metallic tactile sensors were rugged, uncomfortable to wear and incapable of producing accurate measurements. Professor Shimojo wrapped a thin and soft tactile sensor around a cyber glove developed for measuring shape (See photo.) and thus developed a system which could simultaneously measure both shape and movement and produce image data.

Many corporations use this grip function measurement system to determine the best shape of an electrically powered tool grip or the steering wheel of a car that will be easy to use and reduce fatigue, or to determine the most comfortable stairway banister height for the elderly.

Mr. Shimojo continues to develop even more advanced tactile sensors.

There are two ways we grip things. One way is by applying strong pressure, while the other way is by tenderly fondling an object. To research the latter, an even softer, comfortable sensor similar to a silk glove must be developed. If such a sensor can be developed, the intricacies of the human touch can be clarified, such as the touch of massaging. Which reminds me of a world renowned sports trainer and Chinese aquapuncturist who can identify an injury within 1 millimeter of its location by closing his eyes and tenderly stroking the body of an athlete. Since normal people can only differentiate physical stimulation at an accuracy of 1 to 2 millimeters, would this imply that the acquapuncturist is only imagining things?

Though its true that a person's tactile sensation itself is not so precise, research shows that the accuracy is improved to the micron level just by moving the finger. Why is possible feel sensations that would normally overwhelm the capacity of a sensory receptor?

Human fingers contain about 50 sensory organs per one square millimeter, while there is only 1 nerve fiber per square millimeter. 50 against 1. Why does such waste exist? Based on an engineering model analysis, I have developed the following hypothesis. The signal is product sum of products calculation on the nervous fiber to comprise a spatial filter.

Let's take sound as an analogy to simplify the explanation. A sound is actually a combination of multiple sounds having different frequencies and noise. But each sound has a basic frequency that clearly identifies it. If the frequency is likened to a series of minute ripples on the surface of an object, each different from the other, by filtering the waves, a regular unique wave can be extracted.

Interestingly, by changing the motion speed of the finger, the filter characteristic changes, and a different frequency can be extracted.

Based on this engineering model, a prototype active tactile sensing system was developed and tested to confirm that this improved the ability for spatial resolution.

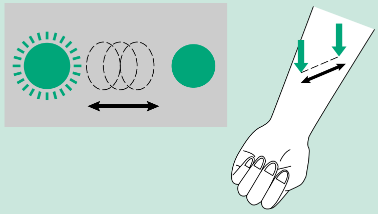
This does not imply however that this model is identical to a human beings' tactile sensory mechanism. I guess this is just a simplified version of a set of characteristics that were extracted.

From a bird to an airplane. Rather than just mimicking the body, the elements should be identified and then applied to an engineering model. This reporter came back with the impression that a monumental first step has already been taken.

In wrapping up this interview, Mr. Shimojo stated, "It has been 20 years since I first began my research into tactile sense. As a life work, I hope to continue to this research."

Tactile Sense and Illusion

Looking at the red lamp of an alarm, it almost appears as if a point is moving between two lamps. This is called apparent movement. The same illusion occurs with tactile sensation. Close your eyes and keep stabbing your arm on two points alternately. You will feel the stimulation moving between the two points. By applying this illusion, a display that can show characters with a minimum number of pins is being developed.



On top of the cyber glove which measures the shape of the hands and fingers, the sensor glove made from a thin and flexible tactile sensor is installed. (A total of 103 pressure points were detected.)

It is possible to analyze the type of grip, pressure distribution, location of wrist, and the motion image data.

Makoto Shimojo

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Born in l951. Previously served as the chief researcher of the Human Environment System Department, Information Transmission Function Research Section, Life Engineering Industrial Technology Research Laboratory. He received the Best Academic Paper Award at the IEEE International Workshop RO-MAN '98. for FY l997 (Robot and Human Communication).

http://www.cis.ibaraki.ac.jp/shimojo/