Impact Objectives

- Explore how humans and nature unknowingly cooperate by interacting through tactile haptic interaction
- Study communications via tactile senses using general computational science

Computing the universal language of nature

Associate Professor Yasuhiro Suzuki leads a team embarking on exciting research regarding the tactile sense. Here, he talks about how he came to be involved in the broad field of tactile science, and his proposals for using a tactile score to inform future research

How did you come to be involved in the research field of tactile science?

At the beginning of my career, I was studying artificial life. My subject was the origin of life. I proposed an abstract chemical system, called Abstract Rewriting Systems on Multisets (ARMS), which could realise chemical evolution from chemical reactions to protocells in ARMS. Over time, the single cells evolved into multiple cells: evolution began from the metabolic system, and eventually, functional differentiation occurred. I came to develop this system as a computational system. As with breeding, users perform calculations indirectly by changing the environment, for example, which promotes evolution so that the system performs the desired calculations. This research led me to be interested in computations that harness the system they are in by modifying the environment.

For instance, there is a clear symbiosis between highly pathogenic influenza and humans. The influenza virus must infect to live – it does not infect people to kill them as this will destroy the host and therefore it. Influenza has the means to control the evolutionary mechanism – if pathogenicity were accidentally increased, the virus would perish with the host and, as more and more people died, the highly pathogenic flu would become extinct. Thus, we conducted research on this flu based on the concept of harness. The cause of death from highly pathogenic influenza is viral pneumonia, which sometimes causes acute respiratory distress syndrome (ARDS), for which there is no effective treatment. We wanted to understand how ARDS causes death, to elucidate the mechanisms of highly pathogenic flu - of how it ensures it does not lead to its own extinction. We confirmed that the processes of ARDS, which were caused by a loss of signals to the immune systems, as a result of proteins carried by highly pathogenic influenza (which may one day lead to effective treatment for ARDS).

But when it comes to my current area of focus - both chemical reactions and influenza viruses are tactile interactions between molecules. The natural world is full of tactile interactions, and it can be considered a universal language. Ultimately, all of this led to my interest in understanding how humans and nature unknowingly cooperate by interacting through tactile interaction.

You are also involved in sensory communications, or communications via tactile senses. Can you talk a little about what you hope to learn through your research in this area?

Sensibility or sensitivity is the quality of being able to appreciate and respond to complex emotional or aesthetic influences. It is related to sensations that are transmitted or perceived by the senses. So, sensory communications are those that are transmitted by communication via senses, including tactile sense. While words, characters and language uniquely convey logic and data, the sense of touch uniquely conveys sensitivity. Thus, communications via tactile senses can be said to be a communication of sensibility. In order to elucidate the universal language of nature, we study communications via tactile senses using general computational science, which focuses on understanding nature as algorithms. The research mission is to understand haptic interaction. Sensitivity can be extracted from arbitrary time series data, which means sensory communication is possible between living systems and non-living systems if some time-series data, such as sensor input/output, is present.

One of your projects is proposing a Tactile Score as a method to inform and connect the multimedia sensibility to the Internet of Things (IoT). Can you provide a brief overview of the methods you have used for this research?

The Tactile Score is the foundation of all our projects. Without Tactile Score, none of our projects could exist. To elucidate the universal language of nature, we studied tactile interactions as algorithms using general computational science methodology. Although algorithms can be used to describe time evolution, we were surprised to find that there is almost no research concerning time evolution in the tactile sense.

For instance, the sense of hearing has a musical score, while the sense of smell has a variety of methods to describe time evolution, such as ingredients in perfume. For taste, food recipes are an obvious method, but no such time evolution exists for touch. Musical scores were established in the middle ages, but in the tactile sense, there is no general description to quantify changes over time. The only exception might be how massages have evolved, but these are obviously less well documented than methods for corresponding senses.

Thus, we proposed Tactile Score to describe tactile sensations that change over time. In the tactile sense, softness and roughness are important elements, but since each unit and response time are different, it is difficult to describe them uniformly. We therefore discarded a variety of parameters and, after some trial and error, we confirmed that it could be sufficiently described only by the time change of the vertical pushing force. While in music, a score describes the pitch and length of the sound, the Tactile Score describes the change in magnitude and duration of the vertical pushing force; both softness and roughness can be expressed using Tactile Score.

What is the potential impact of your research?

The technology and computational systems we use enables sensuous communication, irrespective of whether the communication is from organisms or inanimate objects.

An example of actual tactile communication. Mr Kawasora (visual hearing impairment) sketches a tactile taught massage.

Moreover, the methods we use can be combined with many information systems, such as the IoT, Virtual Reality and Brain Machine Interface. Sensitivity processing can be added to the current system too. As it stands, we are able to make logical and analytical judgments based on verbal processing, where the technology corresponds to the left brain. Ultimately, we can combine our sensitivity processing based on non-verbal (tactile) processing with the current left brain-based technique so that every system can have the left and right brain

Finally, can you tell us how important you think it is that there is support for early-stage researchers through projects?

It is crucial. Fortunately, current typical support grants for young researchers are adequate. However, we need to give some thought to developing novel support systems which enforce a researcher's potential to produce innovative ideas. In Japan, universities can be quite rigid in their thinking, as they tend to only be interested in ideas that have intrinsic economic benefits or can secure publication in big journals. This means that many interesting ideas fall by the wayside and are simply ignored - this has the result of demotivating young researchers. When you consider that these people are the next generation of scientific research, there is certainly room for improvement, at least where to support them is concerned. ▶

Understanding nature through algorithm

Researchers based at ***Nagoya University*** *are dedicating tremendous resource to the development and promotion of tactile science. The team's investigations branch off into a wide variety of different areas of focus, including computational science, sensory communications and body idiomatisation*

Associate Professor Yasuhiro Suzuki is working with a team from the Nagoya University in Japan to conduct the research based on general computational science. One of the key tenets of his work is attempting to improve our understanding of nature through algorithms. 'For centuries, nature was seen to be unstable and incapable of being quantified,' he states. 'However, modern thinking has shown that algorithms can stabilise unsteady nature to repeatedly cause the same phenomenon.'

GENERAL COMPUTATIONAL SCIENCE

Thus, Suzuki and his team proposed general computational science as a means to understand nature as an algorithm. The algorithms have been used to understand physics, chemistry, biology and medicine. They perform numerical calculations and simulations of equations on a computer, as such they are not designed to stabilise a natural system. 'Everything started with a chat in a sushi bar with Professor Masami Hagiya,' says Suzuki. 'We were discussing how we might imbue computer science with a semblance of romance. Over the course of the conversation, we conceived of natural computing that connects nature and computation.'

Shortly after, Suzuki and Hagiya established the Special Interest Group of Natural Computing. Suzuki considered nature and computation for more than ten years and eventually came up with the idea of general computational science, which was based on a concept by the Japanese naturalist, Kumagusu Minakata. 'In the general computational science, the team defines an algorithm as sequences of executions that can repeatedly cause the same phenomenon,' he explains. 'When they obtain such an algorithm, they can leave the elucidation of the mechanism to a conventional scientific method and move on to something else.' In addition, if the reproducibility of the obtained algorithm is sufficiently high, it can be applied to engineering and industry. For example, if an excellent skill of a craftsman is converted into an algorithm, engineering and industrial applications can be applied in parallel with scientific clarification of the skill.

Ultimately, this method of general computational science will be able to discover many phenomena, which Suzuki can repeatedly cause by the algorithm. 'So, by combining the general computational science with conventional science and engineering, we make it possible for phenomena to be observed using scientific methods in an efficient way,' he highlights. Because engineering and industrial applications do not have to wait for the elucidation of scientific mechanisms that generally require time, the progress of science and technology can be accelerated.

SENSE OF TOUCH

The tactile sense is one of the five traditional senses of the human body, along with sight, hearing, smell and taste. The tactile sense is generally recognised by touch, which is mainly found in the skin, although the sensitivity of different parts varies wildly across the body. For instance, the end of the elbow is usually very insensitive to touch, but the skin across the stomach or on the back of the forearm is far more sensitive.

Despite the fact that the sense of touch is one of the five main senses, the tactile sense is generally underserved by the scientific community. However, in recent years, the field of tactile science has gained more traction, as researchers look to develop our understanding of the mechanisms by which it works - but also how it relates to other senses to change or enhance an individual's experience.

> *'By combining the general computational science with conventional science and engineering, we make it possible for phenomena to be observed using scientific methods in an efficient way'*

One researcher who has dedicated his life's work to developing and promoting tactile science in a myriad of ways is Associate Professor Yasuhiro Suzuki, from the Department of Complex Systems Science at the Schools of Informatics and Science, Nagoya University. He is leading several projects simultaneously, which explore different areas of tactile sense, some of which are interrelated, although some exist independent of the others.

TIME SENSITIVITY

One of the most fascinating areas of Suzuki's research is concerned with understanding time changes in the tactile sense. 'The sense of hearing has musical scores, which have evolved over centuries, while the sense of taste can look to how ingredients in recipes have changed from years ago to the present day,' observes Suzuki. 'But in the tactile sense, there is no general description that can quantify changes over time.'

With that in mind, Suzuki and his team developed the Tactile Score. It is something that underpins every single project Suzuki is involved with, which should go some way to explaining its importance. Among his many other talents, Suzuki is a skilled computational scientist, which came in handy when developing the Tactile Score. His team studied tactile interactions as algorithms using general computational science methodology, which enabled them to describe tactile sensations that change over time.

Put simply, the Tactile Score describes the changes in magnitude and duration of the force pushing an object, and both softness and roughness can be expressed using the Tactile Score. 'When a hard object is pressed, the normal force does not change with time, but when it is soft, the normal force changes with time,' outlines Suzuki. 'When the pushing object is soft, the normal force is weak in the beginning, but eventually increases. Thus, it can be described as 'hard' if the change over time is small, and 'soft' if the change over time is significant.'

Armed with these findings, Suzuki extracted multimedia data from the time variation of the intensity and size described by the Tactile Score, and was able to extract sensibilities that could then be converted into information (using the Tactile Score as an intermediate language), known as TS-bit. The information can be output as an audio file, which means that tactile sensations by hand can be digitised.

HAPTIC VIBRATION DISPLAY

One of Suzuki's current research focuses is on haptics. 'Haptics is the science of applying tactile sensation to human interaction with computers,' he explains. Haptic devices are those that involve physical contact between a computer and a user, such as a joystick that vibrates to reflect what is happening on the screen. 'After we have launched TS-vibrotactile (vibrotactile transformed from Tactile Score), we realised there are no devices which can display TS-vibrotactile, so we created the Haptic Vibration Display (HVD) from scratch. Hence, our haptic device, HVD, is very much different from ordinal haptic devices, such as a joystick or a virtual soccer ball, in terms of structure, design and functions.'

The team have produced some outstanding results confirms Suzuki. 'We have established technology to output TS vibrotactile (very low-frequency sound) from smart devices such as smartphones without using dedicated sound devices such as audio amplifiers and frequency modulators.'

Validation of the findings

The team used the Tactile Score to mathematically analyse a tremendous amount of data. They took data from a massage, which more than 20 million customers had purchased, and transcribed it. They found that there exists a grammar for massage and, because this grammar is highly versatile and capable of describing the majority of massages, it is verified for quantifying the hand tactile sense and vibration tactile that has been digitised (TS-vibrotactile). 'The Tactile Scores or tactile stimulations that follow the tactile grammar are called the rational Tactile Score or rational tactiles,' notes Suzuki. 'On the other hand, the scores that are not supported by the grammar are called the irrational Tactile Scores or irrational tactile.' There were several different areas which the team sought to verify through a variety of methods.

Tactile Sense By Hand

They compared before and after facial images using rational Tactile Score, which confirmed that the contours were reduced and the brightness of the skin increased. 'We also investigated the changes in stress markers when a facial massage was performed with rational and irrational touch,' says Suzuki. They then used an enzyme called amylase, which is contained in saliva, as the stress marker. As a result, the researchers found that the massage with the rational Tactile Score reduced the stress, while the massage with the non-rational Tactile Score increased stress.

Vibration Tactile Sense

The team generated TS vibrotactile sensations from a reasonable Tactile Score and an irrational Tactile Score. 'A TS vibrotactile sensation was applied to one central part of the palm, and brain activity was measured by the near infrared spectrograph, NIRS,' outlines Suzuki. 'A TS vibrotactile sense with a reasonable tactile score confirmed that the brain activity increased statistically.' Such a phenomenon could not be confirmed in an irrational case.

Microsoft Face API Age Estimation Using Artificial Intelligence

A verification experiment of TS vibrotactile was conducted on subjects in their 70s who used HVD for two weeks. The team estimated the age of individuals from images taken before and after using the age estimate system produced by Microsoft. It showed that there was an average anti-ageing effect of 3.6 years, which is statistically significant, and a physiological analysis of the skin showed that these were largely increased in the density distribution of collagen. 'We also found that there was a peripheral blood flow increase and an elimination of sleep disorders,' says Suzuki. 'Medical experts from the Tokyo Medical and Dental University evaluated the results and found that lower brain function contributed to the improvements.'

'The findings from this research led to an interesting side effect - body idiomatisation by massage, namely, that the experiment led to a change in the subjects' social activities.' The women who formed part of the experiment rarely applied make-up or cared about the clothes they wore. Suzuki and his team noted that this changed after their experiments, with many of them becoming more social and some even starting new jobs. Suzuki spoke with one of his friends, Professor Kaori Karasawa at Tokyo University, who became interested in the research. Together, they realised that while the HVD verification experiment improved the condition of the skin on the subjects' faces, they also learned that changes in the outer surface can change the inner and social aspects of a person. 'These results suggest that, unlike make-up, self-image changes due to changes in one's own body,' says Suzuki. 'It shows that tactile communication can change the condition of the body, which can affect social behaviours.'

The SHOKKAKU Project

***SHOKKAKU** is a new tactile project that handles tactile sensations that change with time. Using a tactile score as an intermediate language, the team hopes to one day be able to enable tactile distribution through TV, radio and the internet*

In a world of black mirrors, being the screens of our televisions, computers, smartphones and other devices, there appears to be a heightened focus on the audiovisual aspects of any of the media that individuals consume. Whether it is streaming music through Spotify and Apple Music, or connecting to Netflix and Amazon Prime, etc., the chief focus for individuals in their spare time is to consume audiovisual media. In contrast to this, the SHOKKAKU project has been established by Associate Professor Yasuhiro Suzuki, from Nagoya University in Japan, and collaborators from the Tactileology Society Japan and Tactileology Association Japan. SHOKKAKU (which means tactile sense in Japanese) is a new media project where touch is given priority over audiovisual.

'As a demonstration experiment of this technique, we collaborated with artists and we transformed body movements into Tactile Score and generated TS vibrotactile simultaneously and deliver to audiences,' observes Suzuki. 'Amazingly, audiences not only view body movements but also can feel tactile body movements as TS vibrotactile at the same time.'

This technology made it easy to combine TS vibrotactile and music or video; this is the birth of a new tactile-audiovisual media. 'As a demonstration experiment of this technique, we collaborated with artists and we transformed body movements into Tactile Score and generated TS vibrotactile simultaneously and deliver to audiences,' observes Suzuki. 'Amazingly, audiences not only view body movements but also can feel tactile of body movements as TS vibrotactile at the same time.'

THE TS VIBROTACTILE AND DEEP MICRO VIBROTACTILE

As it stands, there is no general-purpose device that outputs tactile sensations that change over time. Thus, the team developed a variety of HVDs for presenting the TS vibrotactile that is generated by the tactile score. 'Until now, tactile sensation has been presented by hand and vibrotactile, but musician, Goro Noguchi has proposed a method to embed vibration components in music and speech through joint research,' explains Suzuki. Noguchi and Suzuki conducted a Deep Micro Vibrotactile (DMV) demonstration experiment using

Goro Noguchi (national singer) and Norimasa Kawasora (deafblind) at the establishment commemorative symposium of Tactileology Society Japan and Tactileology Association Japan (December 5, 2019, The University of Tokyo)

a concert hall. They confirmed that DMV enhances the impression of sound through acoustic measurements and approved in a questionnaire that 10 out of 12 participants were impressed. Previous studies have shown that DMV increases the influence of music, evokes emotions, increases concentration and deeply relaxes. DMV has the potential to evolve music from just entertainment into functional music that can apply to things such as beauty or medicine.

Suzuki, Noguchi and their colleagues have recorded and analysed natural sounds. They investigated natural sounds in cities, fields and places where people have gathered since ancient times, such as sacred forests, shrines and temples. 'We confirmed that natural sounds in those places include DMV, and through acoustic analysis of natural DMV that the acoustic tactile sensation of DMV varies greatly depending on the location,' says Suzuki.

A BEAUTIFUL MOMENT

Imagine a world where a person who cannot hear is able to feel the music through the conversion into TS vibrotactile information. This is something that Suzuki has helped to make possible and it ranks as one of his proudest achievements. 'Norimasa Kawasora, a tactile dominator (visual and hearing impaired), lost his hearing at an early age. The memory of his mother's singing voice and lyrics meant he had a passion for music, even if he could no longer hear it,' says Suzuki. 'He experienced music as it was converted to TS vibrotactile through HDV applied to his chest. He looked very happy with a full smile. I was so happy to have done this project at that moment.'

NEXT STEPS

Suzuki and his team believe that the mission to gain an algorithmic understanding of tactile communication has begun. 'The next step, from a generational computational science standpoint, is to build a human/natural computing system with TS-bit as the tactile input algorithm and biological response as output,' he confirms. If the research is successful, it will be possible to control living organisms and natural systems indirectly through tactile communication.

Until now, there was no general method to verbalise non-linguistic information. Tactile Score succeeded in verbalising non-linguistic information. 'The reason is that I realised tactile sensation is a medium of non-verbal information,' confirms Suzuki. 'In the future, much non-linguistic information will be verbalised as a T-bit by Tactile Score, and the old analog information, which has been discarded under the name of computerisation, will be revived by Tactile Score technology.'

Over the last century, humanity has moved towards the digital and virtually abandoned analog information and technology. Suzuki hopes that by realising his human/natural computing system vision, he will 'restore the power of human hands that are tactile wisdom' that humans and the natural world originally had. With the cooperation of the Japan Medical Association, empirical research will start soon on the application of Tactileology technology to dementia, including Alzheimer's disease.

Project Insights

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COLLABORATORS

- *DMV*: Goro Noguchi (musician)
- *Art*: Professor Ishibashi Yoshimasa (Kyoto City University of Arts), Norihito Ishi (Choreographer, Butoh dancer), Atsushi Heki (Choreographer, Nichibu and contemporary dancer)
- *Science & Engineering*: Professor Masami Hagiya (Computer Science, The University of Tokyo), Professor Masahiro Ohka (Tactile Robotics, Nagoya University), Professor Masaaki Sakagami (Physics, Kyoto University), Professor Kazuko Ren (Nursing, Kyoto University), Professor Kaori Karasawa (Social Psychology, The University of Tokyo)

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