5-3 Multi-Sensory Interaction Technology and its System Application

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This paper describes multi-sensory interaction technology developed in NICT. First, we describe the aim of multi-sensory technology and the overview of the multi-sensory interaction system. Second, we describe the methods for extraction and display of 3D images, haptic information, contact sounds and aroma, and the interaction techniques that can naturally provide the integrated sensory information to humans. Finally, the multi-sensory contents that we have produced are explained, and future issues and system applications of the multi-sensory technology are discussed.

Keywords
Multi-sensory integration, 3D image, Contact sound, Haptic information, Aroma

1 Introduction

We receive all kinds of information regarding the outside world through our sensory organs such as our sense of vision, hearing, somatosensory information (touch), smell and taste. Not only do we receive such information passively, but also actively, by working in the outside world with our hands to operate things interactively. Most conventional information and communications technology has not been able to convey information through the senses of touch, smell and taste nor been able to actively work with displayed sensory information, since such technology has mainly focused on letters, sound and images. Multi-sensory technology could be said to challenge the limits of conventional information communications by enabling natural and real information communications through multi-sensory information equal to that of the existing communications in the real world.

First, in this paper, **2** discusses the aim and overall structure of multi-sensory technology, and the technology for displaying sensory information for images, haptic information, sound and aroma. Next, **3** is an overview of contents creation technology for multi-sensory information developed up to the present. In **4**, we discuss future issues and applications for multi-sensory interaction technology and finally in **5**, we provide a summary of the issues raised in this paper.

2 Overview of multi-sensory interaction technology

2.1 Aim and overall structure

The aim of the multi-sensory technology being developed by the authors in the research group can be summarized as 1) the integration of multi-sensory information, 2) the utilization of actual data and 3) natural interaction. First, 3D images, sounds, haptic information and aromas are integrated and displayed as multi-sensory information. In other words, users can verify haptic information (hardness, softness and roughness) by touching 3D objects in their hands, feeling the presence and nature of the object from contact sound when toughing the object and, at times, smelling the aroma. Although users are able to freely create information similar to that of CG (computer graphics), data of the actual object is extracted and reproduced in order to display these types of multi-sensory information in a more true to life manner. Furthermore, while it is currently difficult to extract all actual data including aroma, contact sound can be extracted with the 3 dimensional structure and surface texture of the actual object. Structural data provided by using laser measurements and imaging data of the surface texture is integrated as one 3D model and a sound model is created by analyzing contact sound and extracting fundamental sound parameters.

A multi-sensory interaction system (Fig.1) has been created to enable natural interaction for extracted and constructed 3D and sound models of actual objects. This system comprises of a 2 view 3D display device, force feedback device, speakers (or headphones) and an aroma injector. By touching the 3D image of objects using the force feedback device, contact sounds and haptic information (sense of hardness, softness and roughness) are naturally conveyed to the user in real time and virtual 3D objects can be moved and transformed. Furthermore, aromas can be displayed when necessary. Display technology for all multi-sensory information is described below.

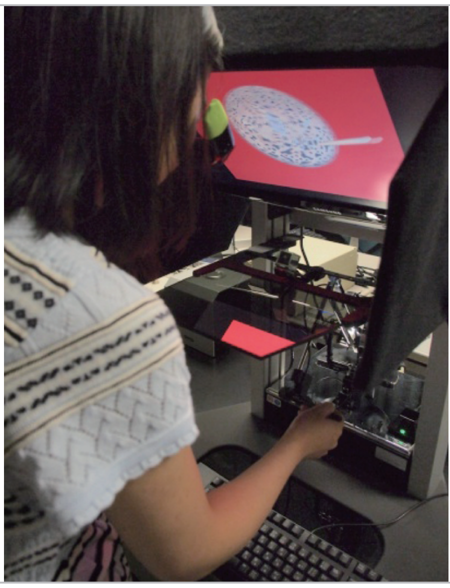

Fig.1 The multi-sensory interaction system

2.2 3D image and haptic information generation

The image of an object is generated from its left and right views alternated at high speed and shown on the display. This image is then reflected on a half-reflection mirror enabling the user feel that the 3D image is actually in his/her hands by observing the object though shutter type eyeglasses. Haptic information is displayed using a force feedback device (Phantom Premium 1.5) and the user can feel the hardness, softness and shape of the surface by touching the virtual 3D object with the stylus (pen) for this device. This is achieved by the force feedback device positioning sensor detecting the collision of the stylus point and the virtual object and the devise's internal motors returning the appropriate reactive force.

The structural data is either created by CG or extracted by measuring the object with a laser digitizer. In the case of actual data, not only is the 3 dimensional structure of the surface extracted but the object images are captured from various viewpoints and pasted on the surface of the object as a textural image. Haptic information is generated by setting the rigidity and friction coefficients. Currently, these hapitic information parameters cannot be measured as they are set using Reachin API. Furthermore, in order to align the 3D image and haptic information of the object in a 3 dimensional space, the three axis directions of the object image are expanded, contracted, translated, and rotated and the stylus image is rotated so that calibration is performed to visually match the actual hand-held stylus and virtual stylus.

2.3 Contact sound generation

Particular contact sounds are usually generated in accordance with the substance (metal, wood, resin, etc) of an object when it comes into contact with another object. Therefore, it is conceivable that a virtual object will appear more real when a contact sound is generated. However, it is not sufficient to merely play back a recording of the sound of an object coming into contact with another. In order to feel the sensation of natural sounds, it is necessary to generate contact sounds that differ according to surface characteristics of the place touched by the user and the strength of the contact made. In addition, it is necessary to generate appropriate contact sounds based on the type of contact (tapping, scratching and stopping, etc) in a smooth manner in real time. In order to generate such natural sounds that match the actions of users, the authors developed a contact sound generation method based on the modal synthesis method[1]. This method assumes the particular oscillating structure of the objects as numerous sinusoidal modes and describes the characteristics of the vibrating body (sound model) through the frequency, attenuation coefficient and amplitude. Sound models are constructed by selecting dozens to hundreds of frequency modes using the discrete Fourier transformation and estimating the frequencies, attenuation coefficients and oscillation parameters of each mode using the least squares method after extracting contact sounds from actual objects in an anechoic room. Contact sounds for virtual objects are created by measuring the conditions reaction force in the normal and surface directions, and its contact time of contact action (position, strength and the way of contact) and synthesizing such contact sounds in real time by convolving the contact information and the impulse responses of each sound model constructed in advance. In addition, smooth sound transition is generated by linear sum estimations of tapping and scratching sounds in order to provide natural sounds to users.

2.4 Releasing aroma

Aromas not only make the target object seem more real, but also help convey the moods and emotions of the relevant situation. In fact olfactory information has a strong connection with pleasant and unpleasant emotions. Fragrances are not only used in food and beverages but also cosmetics, detergents, hair styling spritz and aroma therapy in order to provide pleasantness. By providing aromas in addition to images, sound and haptic information, the authors of this paper have explored new possibilities for the display of multi-sensory information.

The difference between aromas and other technology used to display sensory information is the difficulties in temporal and spatial control of aroma. Aromas require chemical substances to directly reach the nose. Generally, aroma substances diffuse in all directions when simply released. Not only is it difficult to supply to the nose, it is necessary to either clear the air in the room or get rid of the smell using other methods once an aroma is diffused. Furthermore, humans quickly get accustomed to smells, and aromas become ineffective over long periods of time. Consequently, it is ideal to provide aromas to the nose of the users for only the required amount of time without the relevant aroma diffusion. In other words, an aroma spatial-temporal controlling function to release aromas in a particular space and for a determined time is required. In addition, in order to provide various types of aromas, it is necessary to create the smallest devise possible for the release of one aroma.

The authors have thus created the “Micro-Aroma-Shooter” an ultra compact aroma ejection devise which can be used to enable aromas to be released with these kinds of spatial-temporal restrictions[2][3]. This device comes in the shape of a 20mm sided cube with a tiny hole for ejecting certain aromas to the noses of users at any time. Although there are already ink-jet type devices which release liquids containing aromas, this prototype device created by the authors enables aromas to be carried a greater

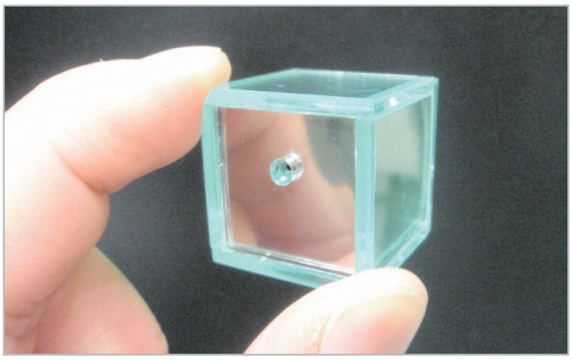

Fig.2 The ultra compact aroma ejection devise “Micro-Aroma-Shooter”

distance by ejecting air containing aroma substances. Furthermore, a device that projected air packets containing aroma substances over a distant range has been developed, however, the device emitted loud sounds and reducing its size remained a fundamental problem. Conversely, the "Micro-Aroma-Shooter" is compact and ejects air containing aromas with virtually no sound. There is minimal diffusion of the air it ejects and aromas do not linger around the user if emitted in a short time. Therefore, this device is suited for individual use and does not require the elimination of odors.

Aromas are most effective when used in conjunction with images, sounds and haptic information. In everyday life, olfactory information is often acquired with other sensory information while performing certain actions. For example, there is a sense of softness and a floral fragrance when a rose is picked, a crackling sound and sweet aroma when hot baked sweet potato is opened, a dispersion of droplets and sour aroma when a lemon is squeezed and the sound of can being open and a fragrant aroma when a can of coffee is opened. The use of a multi-sensory interaction system enables certain aroma stimulus to be presented with vision, hearing and somatosenroy information for certain actions and operations, and various daily situations to be reproduced.

3 Multi-sensory interaction content creation

In order to demonstrate the effects of the multi-sensory interaction technology described in **2**, it is necessary to create and implement actual multi-sensory content and perform many human trials. Consequently, multi-sensory content containing various functions was created and exhibited at numerous events. Tens of thousands of people responded positively to trials and the technology was covered widely in domestic and overseas newspapers, television programs and on the internet. In this section, we will provide an overview and the aim of multi-sensory content developed up to the present.

3.1 Multi-sensory content (1): "Drum and Bell"

The first content created was a "Drum and Bell". This was created in autumn 2007 and a trial demonstration was conducted at CEATEC and on the occasion of the research fair at NICT in the same year. The aim of this content was 1) the extraction of 3D data and images from an actual drum and the creation of a suitable 3D model, and 2) the extraction of beating and scraping sounds (on the side of the drum), the creation of a sound model and the validation of a control algorithm that enables the natural generation of sounds. 3D structural data and images was extracted by installing a small drum on a turntable and measuring and extracting the 3D structure and textural images from different directions using a laser digitizer (Konica Minolta VIVID) and the 3D model was created by separating the skin, wood and nails. The beating and scrapping sounds of the drum were recorded in an anechoic room, the fundamental frequency mode was extracted by analyzing the frequencies and the oscillation and attenuation parameters of each mode were calculated. On the other hand, bell sounds were analyzed using a bell sounds that differed from an actual bell and the fundamental parameters were calculated to produce more effective tones. In regard to contact information, the roughness of the surface can be reproduced from the minute 3D structure extracted by the digitizer. However, the elastic force of the skin was established by manually setting the elastic parameters while comparing it to the actual contact information.

This content generates natural sounds in real time according to the contact method of the drums and bells. In other words, the sound of beating the skin of the drum and scraping the side of the drum was generated without virtually any delays. Furthermore, the strength of the sound changed in accordance to the strength of the beating of the drum while the sound only slightly differed when the drum was hit at its center and on the edge. Although a small sized drum was used for the recording, the basic frequency was set slightly lower in order to make

Fig.3 Multi-sensory content "Drum and Bell"

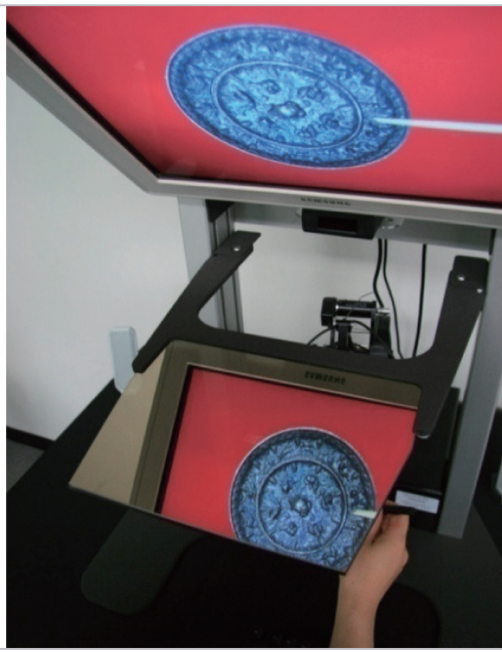

Fig.4 Multi-sensory content "Mirror; Kaiju-budo-kyo"

the sound of the drum beat sound like a large-scale drum. In addition to the drum skin, a function to generate the particular contact information and sound of making contact with the wood and nails of the drum was also implemented. Conversely, as it takes longer for the sound of the bell to attenuate than that of the drum, a function to gradually stop the bell ringing when the stylus is placed on the surface of the object was implemented. Through conducting numerous trials involving various interactions by many people, this technology is now capable of providing people with a real sense of natural and reality based multi-sensory information.

3.2 Multi-sensory content (2): "Ancient mirror; Kaiju-budo-kyo"

The second multi-sensory content is the reproduction of the "Mirror; Kaiju-budo-kyo"[4]. This bronze mirror was excavated from the Takamatsu-zuka Tomb and has been designated as an important cultural property. Casted in China, legend has it that it was brought to Japan by a diplomatic mission from the Tang court (702-704). The back of the mirror has a grape and arabesque design with imaginary beasts, birds and insects. The first version of the multi-sensory content of this item was completed in June, 2006 and after numerous improvements, the completed version was put on display on the occasion of the ITU Telecom Asia (Bangkok, Thailand) in September and at the research fair in November the same year. It was then later displayed at a number of other domestic and overseas events (NAB in the United States in April, 2009 and IBC in Europe in September, 2009, etc).

The main aim for creating the content for this item was the application and validation of multi-sensory interaction technology for cultural experience and training. Coming into contact with precious cultural relics deepens understanding of history, heightens sensitivity and enriches lives of people. However, in order to come into contact with precious cultural relics, people must normally go to a museum and look at an exhibit behind glass at limited opening hours. By using multi-sensory interaction technology people can observe a virtual image from different directions and experience a true feeling and sound just like touching the actual object.

Data for the Mirror was obtained with the cooperation of the Nara National Research Institute for Cultural Properties, the caretakers of the actual article. As there is a risk that the actual article (stored in the Asuka Historical Museum) may be damaged through the extraction of data, the Institute performed the difficult task of creating a detailed replica of the original. This replica was a true reproduction of the size, substance, shape and texture of the original and was used to extract data. The 3D structure and image was extracted using a laser digitizer and a high resolution camera. Sound data was recorded by gently tapping the replica in an anechoic room and the sound model was created by analyzing the frequency. Contact information for the sensation of indents and roughness was reproduced using the extracted detailed 3D structure. However, as the substance of the replica was bronze, there was no elasticity.

The content of the Mirror was created with the intention to display both the physical and virtual characteristics. In regard to the physical characteristics, the 3D structure of the pattern on the back of the Mirror and the rusty condition on the front can be felt through the 3D image and contact information, and the hardness of the metal and sense of the substance can be experienced through contact sound. In addition, users can expand the size of the Mirror and feel the detailed surface. Furthermore, by pressing the stylus deep into the edge of the Mirror, users can rotate the Mirror and experience its weight.

Users are also able to create aspects that do not exist in reality through the virtual content. We tried to reproduce the shiny surface that existed at the time of the Mirror's creation. Although the Mirror is made from bronze, it also contains a small amount of tin. Consequently, through the virtual content, the surface of the Mirror can be changed to its original shiny gold surface in an instant. In addition, although the actual surface of the excavated mirror surface is covered with rust, it originally had a smooth mirror surface that could be used as a mirror if polished. The virtual content enables users to feel this smooth surface that existed at the time of its creation and see a virtual reflection of their face in real time. This has been achieved by installing a small video camera in the lower part of the half mirror incorporated in the multi-sensory interaction system and by capturing the user's face image into the virtual mirror in real time. Thus, through fusing the real world information into the virtual world, users can now experience a new type of virtual museum.

3.3 Multi-sensory content (3): "Bursting Balloons"

The third multi-sensory content, "Bursting Balloons", was completed in autumn 2009. Trial demonstrations were conducted at the Keihanna Information and Communications Research Fair in November of that year and at the pre-event of the Umeda Kita Yard Ground-breaking Ceremony and other events held in the following year[5]. The aim of this content was to create a solidity of a balloon that generate a sense of elasticity and emit aromas. Users can expand balloons by touching balloons with the stylus and feel the elasticity by pressing the stylus on balloons. Users can also burst the balloon by pressing the stylus with greater force, hear the sound of them bursting and smell emitted aromas. The 3D structure and image of the balloons was measured and extracted using a laser digitizer on three actual balloons and the sound of the balloons bursting was recorded by bursting real balloons. Balloons of differing sizes were displayed and the elasticity and bursting sound was adjusted accordingly. Three types of aromas (rose, lavender and sandalwood) were inserted into the Micro Aroma Shooter, which ejected different aromas when balloons were burst. The duration of the ejec-

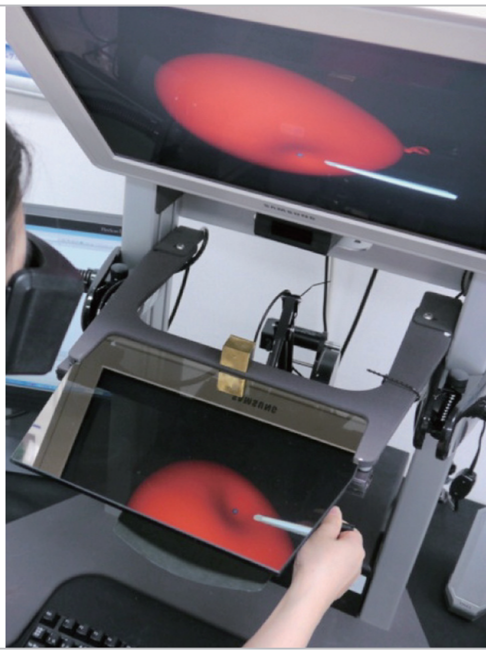

Fig.5 Multi-sensory content "Bursting Balloons"

tion was also adjusted according to the size of the balloon.

Aromas were utilized for the first time for the content of the bursting balloons. The Micro Aroma Shooter is capable of ejecting aromas directly to the nose without dispersal. Although it is necessary to detect the position of the user's nose and eject the aroma in different directions when the user is able to move his/her head freely, the installation of such function involves higher costs. However, ejecting aromas in different directions is not required in our system as the position of the user's nose is almost totally fixed through the use of 3D glasses. This content allows users to experience a reality never seen before since aromas are added to the manual operation of balloons.

3.4 Multi-sensory content (4): "Ginkunro"

The fourth multi-sensory content was the reproduction of the "Ginkunro", a treasure stored in the *Shōsōin*. This content was created to conduct a demonstration for the general public at the "Heijō-kyō Hands-on Learning Center" located at the site of the "Commemoration of the 1300th Anniversary of the Nara Heijo-kyo Capital" held July 31 until September 3, 2010[6]. The "Ginkunro" is a silver spherical shaped incense burner used to provide fragrances to clothes and other items. It is said that it was donated to the Todaiji temple by the Empress Kōmyō (*Kōmyō kōgō*) in the year 756. The surface is engraved with an arabesque design, lions and phoenixes and the top half can be separated from the bottom half[7]. Inside the bottom half is a semi-spherical incense holder of the compass structure with intervening three layered rings, which keeps the incense holder in a constant horizontal position. With the cooperation of the Office of the Shosoin Treasure House, Imperial Household Agency a 3D structure and textural images were extracted from a replica of the "Ginkunro" for the creation of the multi-sensory interaction content. This replica is a true reproduction of the *Shōsōin* treasure created by the silversmith Norio Tamagawa (awarded Living National Treasure in 2010) and silversmith Masami Ichikawa in 2002. Since the replica itself is a precious work of art, contact sounds could not be recorded by directly making contact with the object. As a result, contact sounds were recorded using a silver plate and then synthesized based on the analysis of the frequency.

The aim of creating the content for the "Ginkunro" was 1) the reproduction of contact information for the surface pattern and the internal structure, 2) the provision of an incense aroma as an incense burner function, and 3) providing the simulated experience of a compass function. In order to achieve these aims, the stylus was first applied to the surface pattern to enable the spherical structure, silver substance and contact sounds to be experienced. Furthermore, by pressing the stylus force feedback device deep into the surface and then rotating the object, the top half becomes semi-transparent and the internal three layer ringed structure and ash on the top of the incense can be observed. When stopping the rotation, the Micro Aroma Shooter ejects an aloes wood incense type aroma. The top half of the object is actually not semi-transparent. It is the incorporated virtual function that makes this section visible. Furthermore, when rotating the object, the gyro function that keeps the plate horizontal can be reproduced in real time by the movement of the three layered rings. Thus the application of these new methods to actively experience cultural artifacts demonstrates the future development of multi-sensory interaction technology.

Fig.6 *Multi-sensory content "Ginkunro"*

4 Future issues and applications

The research and development of display technology, extraction technology and communications technology could be raised as future issues for multi-sensory interaction technology. In regard to “display” technology for multi-sensory information, improving the display of all types of haptic information is of primary importance. Existing systems require the use of 3D glasses to display images, however, it is conceivable that these 3D images will be able to be viewed with the naked eye in the future. In particular, in order to properly view 3D images from various perspectives, it is necessary to create multiple unaided 3D images and technology that renders images from various perspectives in real time.

In regard to haptic information, current systems limit the sense of force to one point of the stylus. However, this should probably be expanded to two or more points. For example, if force can be displayed by two points using the thumb and index fingers, the sensation of grip will be generated enabling the hardness and softness of objects to be conveyed in a natural manner. In order to achieve the natural sensation of grip using multiple points, it is important to generate the feeling of hardness. Our research group is currently in the process of developing a prototype grip sensation device that satisfies the criteria for people to feel the hardness of objects through psychophysical experiments (See **5-1**[8] in the footnotes for more details). Furthermore, not only is it important to improve the display of the sense of force, but it is also important to develop technology that displays the sensation of skin. Although devices that display the sense of force are suited to the generation of hard and soft contact information by coming into contact with virtual objects using implements such as styluses, it is difficult to directly convey the sensation of roughness caused by minute indents in an object’s surface using fingers. Consequently, it is necessary to develop technology that displays the sensation of skin gained by directly touching objects with the skin on the finger tips. Also, there is a need to develop technology that displays the sensation of substances (including the sensation of hot and cold) and reproduces stereophony when users touch objects. Even in regard to aroma, technology that provides blended aromas of fragrances is required.

In regard to technology that “extracts” multi-sensory information, there are numerous issues that require future research and development. Currently, the methods used to extract 3D structures and textural images are not sufficient. Noise and data loss remains a problem and the integration data extracted from various perspectives often needs to be performed manually. The development of high precision and automated technology that address these issues is vital. In addition, there are many remaining issues for technology that extracts haptic information. In particular, it is important to develop technology that extracts the elasticity and friction coefficients of the surface of objects. In regard to aroma information, the fundamental issue of how to encode aroma information must be addressed. Even in regard to multi-sensory information communications technology, the development of encoding, compressing and compensatory technology is required to prevent delays caused by the dramatic increase in the amount of information.

As shown above, there are many future research issues still remaining. However, in regard to multi-sensory information interaction technology, it is important to further develop technology that clarifies the multi-sensory cognitive mechanisms of humans and actively utilizes such knowledge. One reason for this is that providing multi-sensory information in a physically equivalent manner to actual objects could continue to be problematic and there is a necessity to develop reproduction technology at a level that is not strange or unnatural to humans. One other reason could be that if the mechanism of how people integrate multi-sensory information to cognize the outside world can be clarified, the most appropriate multi-sensory information can be provided to people without unnecessarily raising the accuracy of devises. In the future, it is necessary to integrate and promote both the technical development of multi-sensory information systems and clarification of the perceptual and cognitive mechanisms of humans.

Multi-sensory interaction technology has a wide range of future applications, for example, 1) education, 2) medicine, 3) manufacturing, 4) electronic commerce and 5) entertainment. In terms of education, the research and development of digital museums is gaining attention. Up until now, important cultural and natural properties that should be conveyed to future generations have been limited to exhibitions in museums, pictorial books and videos. However, by using multi-sensory technology people can interactively experience a greater depth of information that includes touch, sound and smell. Furthermore, in the area of scientific education, people will be able to perform quasi experiments without risk, enjoy micro and macro experiences that exceed the day-to-day senses and deepen their understanding of science in general. If this technology is applied to technical training, it could also contribute to the succession of professional skills.

In the medical field, this technology could be applied to training medical interns to perform operations and simulations prior to operations. Highly accurate medical diagnoses could also be possible by using a stylus on 3D images of internal organs. More specifically, cardiac surgeons have pointed out that examining 3D images of the affected area in detail before performing operations would be great use for difficult operations.

In the manufacturing field, although CAD/CG generated 3D models are currently being used in the design stage of products, images without a physical sensation may not be sufficient. While clay modeling and plaster and resin shape forming with 3D printers are currently available, it takes time and incurs much manufacturing costs to form real objects. By using multi-sensory interaction technology, modifications of product designs can be performed in real time while verifying the detailed textures and meetings can be held while sharing information with designers in distant locations.

In the electronic commerce field, although internet mail-order sales are increasing, product information is not always sufficiently conveyed over the internet. For example, it is difficult to convey the size, feel and comfort of a product in a person's hand through images and sound alone. In the future, if haptic display devices can be made at low cost, people may be able to enjoy internet shopping by feeling the product in their own homes without having to go to a shop.

Finally, in the field of entertainment, although there are interactive games that sense body movements and fitness games currently being developed, these programs have not yet reached the point of providing haptic information. If multi-sensory information including haptic information can be included, more natural and healthy entertainment systems may become more popular.

5 Conclusion

This paper provides an overview of the multi-sensory interactive technology used to extract and display 3D images, haptic information, contact sounds and aroma and technology used to integrate multi-sensory information developed by the authors. It has also described the aims and functions of the multi-sensory content created by the authors up to the present. In the future, the authors aim to promote the improvement of multi-sensory technology in line with the multi-sensory cognitive mechanism of humans and facilitate richer communications.

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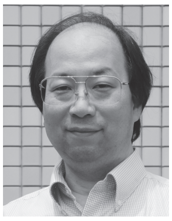

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Olfactory Display, Emotion and Sensibility Information Processing, Syntheis of Functional Gel