Haptic Media

Construction and Utilization of Human-harmonized "Tangible" Information Environment

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Abstract

Our project is based on our proposed haptic primary color theory, and our aim is to construct an intelligent information environment that is both visible and tangible, and integrates real-space communication, a human–machine interface, and media processing. We have succeeded in transmitting fine haptic sensations such as material texture and temperature from an avatar robot's fingers to a human user's fingers. The avatar robot is a telexistence anthropomorphic robot dubbed TELESAR V with body and limbs having 53 degrees of freedom. This robot can transmit visual and auditory sensations of presence to human users, in addition to haptic sensations. Other results of this research project include RePro3D, a full-parallax, autostereoscopic 3D (three-dimensional) display with haptic feedback using RPT (retroreflective projection technology); TECHTILE Toolkit, a prototyping tool for the design and education of haptic media; and Haptic Editor, an interactive editing system for creating haptic-enabled 3D content.

Keywords: 3D, haptics, haptic primary color, haptic editor, virtual reality, VR, augmented reality, AR, human augmentation, augmented human, telepresence, telexistence.

Index Terms: I.2.9 [Robotics]: Operator interfaces; I.3.7 [Three-Dimensional Graphics and Realism]: Virtual reality; H.4.3 [Communications Applications]: Computer conferencing, teleconferencing, and videoconferencing

1 Introduction

This research is aimed at constructing an intelligent haptic information space (haptic media) that integrates communication in real space, human interfaces, and media processing. In other words, we seek to establish methods for the collection, understanding, and transmission of haptic information in real space and its display on humans who are in remote sites. Further, we seek to utilize an information space that feels like the natural space in which people move and act, not only to make remote communication, remote experiences, and pseudo experiences possible but also to build human-harmonized "haptic media" in which creative activities like design and content production can take place like they do in the real world.

The information we acquire through our real lives gives us a holistic experience, fully incorporating a variety of sensations and bodily motions—seeing, hearing, speaking, touching, smelling, tasting, moving, etc.

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However, the sensory modalities that can be transmitted in our information space are currently virtually limited to the visual and auditory. "Haptic Media" that provide sensations like directly touching far away people and objects or touching artificial objects that cannot normally be touched, and transmit texture, mass, warmth, moisture, and other sensory information would expand the current passive information space comprising only images and sounds, to an active and human-harmonized information space where the user can extend his/her hand and feel the presence of the object.

A number of technologies have been developed to build a haptic information space, but they fail to provide a wholesome "experience" owing to two shortcomings:

(1) The technologies can communicate only a select spectrum of haptic sensation owing to the use of ad hoc methods based on an insufficient and still primitive understanding of haptic sensation.
(2) They offer only a narrow definition of haptic sensation, which does not sufficiently incorporate visual auditory sensation and bodily motion.

In order to establish foundation technologies for the "recording and analysis," "transmission," and "playback, synthesis and display" of haptic information, and to build technologies to fully transmit haptic sensation and to bring haptic sensation to a level where it can be treated as information media, much like visual and auditory sensation, this research will

1) expand upon the haptic primary color theory previously formulated by the authors, and further elucidate the haptic sense mechanism in humans, and
2) establish a design method for haptic information combined with visual sensation and bodily movement.

Figure 1 shows the concept of JST-CREST Haptic Media Project (Construction and Utilization of Human-harmonized "Tangible" Information Environment), which started in October, 2009 and will end in March, 2015.

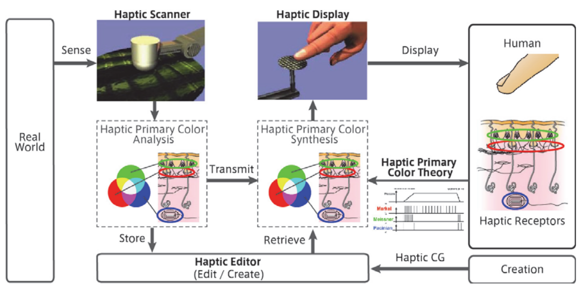

Figure 1: Concept of "Haptic Media"

In this organized session paper, project goal and plan are explained, and interim achievements such as TELESAR V, RePro3D, TECHTILE toolkit and Haptic Editor are shown.

2 THE HAPTIC MEDIA PROJECT

This research concerns the development of a "haptic information space," an information system that makes possible simultaneous delivery of high-resolution haptic, visual, and auditory information. Figure 2 shows the outline of the project.

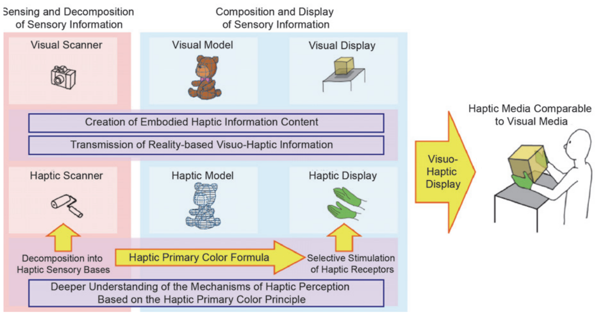

Figure 2: Outline of Haptic Media Project

Some possible applications of these systems would include the implementation of information contents from museums and libraries, as well as training in the fields of medicine and space research. For example, visual and haptic data for a precious object in a museum's collection (normally not available to touch) could be archived in a computer, and users could access the object via a studio-type information space, where they can experience touching the object with their own hands (see Figure 3 left). These systems could also be used in daily life. For example, a shop could store visual and haptic information about all its products, and produce a tangible catalog of its goods. The customer could customize the product on the spot and try it out prior to deciding on a purchase (Figure 3 middle), or two people at distant locations could cooperate in creative activities (Figure 3 right).

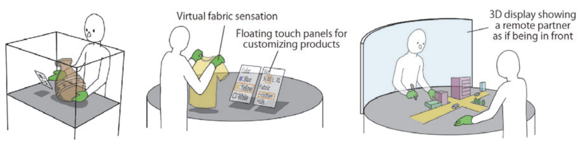

Figure 3: Museum Implementation (left) / Tangible Product Catalog (middle) / Co-Creation (right)

2.1 Haptic Device Design based on Haptic Primary Color Model

Our understanding of human perception mechanisms for processing visual and auditory information continues to progress through biological and psychological knowledge, and sensory information measurement and design methods for presentation based on principles of human sensory perception are already established. It is for this reason that cameras, televisions, and other general-use technologies that measure and present sensory information have been designed and adopted. This research has as its goal the establishment of design methods for processing haptic sensory information based on an improved understanding of sensory mechanisms.

Broadly speaking, human haptic sensation can be divided into cutaneous sensation (pressure sense, vibration sense, thermal sense, and pain sense) and proprioception (kinesthetic sense, position sense, and movement sense). Cutaneous perception is created through a combination of nerve signals from several types of tactile receptors located below the surface of the skin.

If we consider each activated haptic receptor as a sensory base, in principle, we should be able to express any given pattern of cutaneous sensation through the synthesis of these bases. In particular, for pressure and vibration senses, there are four tactile receptors known as the Meissner corpuscles, Merkel cells, Pacinian corpuscles, and Ruffini endings, which are known to activate these senses, each through differing stimuli.

Similar to the three primary visual colors, we have named these haptic information bases the "haptic primary colors" and continue to investigate them. Using this haptic primary colors system as a foundation, the recreation of cutaneous sensation through signal delivery to each sensory base separately (i.e., the selective stimulation of tactile receptors) is a technical concern. We offer selective stimulation of the Meissner corpuscles and Merkel cells through electrical stimulation as one method for the reproduction of haptic primary colors. We have developed a cutaneous sense display capable of high spatial and temporal resolution, and have thereby demonstrated the efficacy of the haptic primary colors system.

A high-density distributed force vector sensor called "Gelforce" has been developed for the quantification of pressure sense information. This development has made possible the collection of real-world temporal and spatial haptic information. By employing these technologies in measurement and presentation, the haptic telexistence system has been devised. The system allows for long-distance transmission of haptic information through the use of a robotic hand with Gelforce embedded in its fingertips, and a "master hand" with an electro-tactile display embedded in the fingertips. Haptic information about the objects gripped by the robotic hand is transmitted to the operator, who is in turn able to smoothly operate the robotic hand [1].

However, although it is already possible to recreate simple conditions like contact and pressure, it is not yet possible to create more detailed natural haptic sensations like the feel of metal or texture of paper. Reproducing natural haptic sensations will require physical information collected from the real world to be "resolve" into haptic sensory bases, and selective stimulation of each type of tactile receptor through composition into the nerve-firing patterns of human tactile receptors. To date, there have been virtually no previous examples of a conversion system for this decomposition and composition, and no effective methodologies have been established. This can be considered one fundamental reason that existing haptic sensory research has been limited to individual tactile sensations.

In this investigation, we expand upon our haptic primary color system. By adding cold receptors (free nerve endings), warmth receptors (free nerve endings), and pain receptors (free nerve endings) to the original four haptic sensory bases and reconsidering sensory activation as a temporal and spatial composition of seven sensory bases, we aim to attain a better understanding of the haptic primary color formula for converting haptic information through decomposition and composition. In order to expand the current selective stimulation method from Meissner corpuscles and Merkel cells to other sensory bases, we must first deepen our biological understanding of haptic receptors and seek a new method for selective stimulation to better understand the nature of temporal and spatial perception of haptic sensation.

We will formulate design principles for haptic sensors and tactile displays that better fulfill the haptic primary color formula, and we will develop transmissions systems for cutaneous sense information that can transmit natural haptic sensations.

2.2 Construction Method of Embodied Haptic Contents

Through the use of computer graphics libraries like DirectX and OpenGL, image editing software, three-dimensional CAD, and other information composition and editing technologies, there exists today an information environment where anyone can freely create visual information contents.

In this investigation, we aim to develop fundamental technologies for the creation of haptic information contents, and to integrate visual information contents into haptic information, thereby constructing a haptic information space. When one touches an object with his/her hand or fingers, the haptic information is barely sensed at all unless the hands and fingers are moved. Only when one moves his/her hands and fingers, the complete haptic information about the object is collected. In addition, haptic sensations in the hands and fingers for the same portion of the same object can differ depending on many factors, including angle, speed, and pressure of touch. The haptic sense differs greatly from the visual and auditory senses in that the perception processes of sensation are mediated by bodily movement. Haptic sensations are thoroughly embodied perceptions. This creates a necessity to control the reproduced haptic information and to respond in real-time to a user's bodily movement throughout the information experience as a part of the expression of haptic information contents.

Kinesthetic sensation can be quantified and presented in real-time through physical simulation technologies, but it is not yet possible to simulate cutaneous sensation in real-time. Using our understanding of human haptic perception, we are working to develop technologies for 1) a haptic scanner that can capture real-world haptic sensations (texture), 2) methods for mapping haptic sensory textures using 3D computer graphics modeling, and 3) technologies to compose haptic sense information in response to arbitrary bodily movements based on the collected haptic sensory textures, as well as seeking to establish a method for building haptic sensory contents with a sense of embodiment. We have previously demonstrated that the resolution and precision of haptic sense information can be improved through the incorporation of haptic motion data.

In this research, we seek to design compression for motion-based haptic sense information as well as simplification of haptic sense quantifications and establish technologies for creation of embodied haptic information contents (Figure 4).

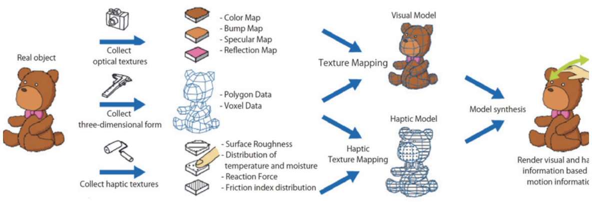

Figure 4: Technologies for Creation of Embodied Haptic Information Contents

2.3 Tangible Visuo-Haptic 3D Display

Touching an object as it is viewed is an absolutely essential element in experiencing the "reality" of the target object. It has been proven that in an advanced stereoscopic display system, if the user cannot extend his/her hand and touch a stereoscopic image, he/she will lose cognizance of the "reality" of the target object and experience a sense of discomfort. As such, there is a strong awareness that together with the popularization of stereoscopic images, it is necessary to fuse visual and haptic information. Since the concept of direct "touch" is not considered for the content offered by conventional visual displays, it is not possible to align the positional relationship between visual information and haptic information. If a head mounted display (HMD) is used, presenting stereoscopic images within the grasp of the user is achievable; however, it is hard to say that a "human-harmonized 'tangible' information environment," which is the object of this study, is suited to such use since HMDs are isolated from the surrounding environment. Assuming that haptic information is available, the ability to provide 3D haptic information at the user's fingertips, and the ability to move one's hands freely without a device at the location where information is provided are requisite conditions. In this study, users were able to take and touch three-dimensional images as well as perform operations while perceiving autostereoscopic visual information using binocular parallax and motion parallax; in other words, a 3D visual/haptic display that can provide "reality" to target objects is being developed (Figure 5).

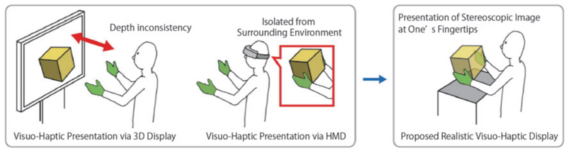

Figure 5: From Conventional 3D Visual-Haptic Displays to a 3D Visual-Haptic Display that Presents Reality

2.4 Construction and Verification of Embodied Tangible 3D System

2.4.1 Transmission of Realistic Tangible 3D Environment

The interim milestone for the present study was to construct a haptic information transmission system between remote locations within a three-year target period. The system was supposed to transmit signals from a haptic sensor in real-time and provide haptic sensations including temperature sensations from a haptic display to achieve a system integrated with visual sensations. We have already succeeded in transmitting fine haptic sensations such as material texture and temperature from an avatar robot's fingers to a human user's fingers by constructing TELESAR V. The final goal is to refine the system.

2.4.2 Creation of Realistic Tangible 3D Environment

The final milestone of this study is to construct a tangible information environment system that presents integrated visual and haptic information. Visual as well as haptic models of real objects will be acquired and added to a database to produce content. Furthermore, demonstrations will be conducted using an experiment system that enables information content to be "experienced" in situations that unite haptic senses, visual senses, and motion.

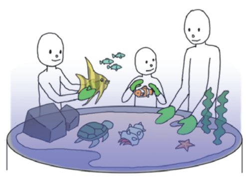

Figure 6: Creation of Realistic Tangible 3D Environment

These demonstrations will reveal that necessary and sufficient haptic information has been acquired, transmitted, and presented. For example, as shown in Figure 6, a demonstration of a haptic aquarium will verify and assess that items such as a sense of touching the fish, as well as water resistance, moistness, and slipperiness are effectively displayed in response to the user's hand movements.

3 INTERIM ACHIEVEMENTS

3.1 Haptic Primary Color Model

Humans do not perceive the world as it is. Different physical stimuli give rise to the same sensation in humans and are perceived as identical, as is shown in Figure 7. A typical example of this fact is color perception in humans. Humans perceive lights with different spectra to have the same color if they have the same amount of RGB (Red, Green and Blue) spectral components. This is because human eyes (retina) typically contain three types of color receptors, called cone cells, each of which responds to different ranges of the color spectrum. They are usually called R, G, and B. Humans respond to light stimuli via three-dimensional sensations, which generally can be modeled as a mixture of RGB, the three primary colors.

This many-to-one correspondence of elements in mapping from physical to psychophysical perceptual space is the key to virtual reality for humans. Virtual reality produces the same effect as a real object for a human subject by presenting its virtual entities using this many-to-one correspondence.

We have proposed the hypothesis that cutaneous sensation also has the same many-to-one correspondence from physical to psychophysical perceptual space, via physiological space. We call this the Haptic Primary Color Model, as explained in Section 2.1. We define three spaces, as shown in Figure 8, namely, physical space, physiological space, and psychophysical or perception space.

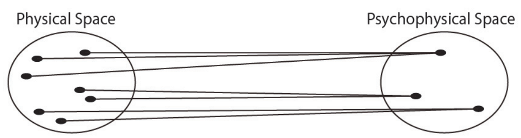

Figure 7: Many-to-One Mapping

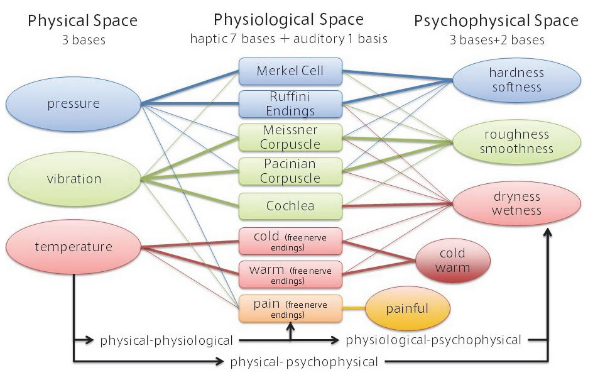

Figure 8: Haptic Primary Color Model

In the physical space, human skin physically contacts an object, and the interaction continues with time. We hypothesize that cutaneous phenomena can be resolved into the following three components at each contact point of the skin: pressure $p(t)$, vibration $v(t)$, and temperature $e(t)$. We measure $p(t)$, $v(t)$, and $e(t)$ at each contact point using sensors present on an avatar robot's hand. Then, we transmit these pieces of information to the human user who controls the avatar robot as his/her surrogate. We reproduce these pieces of information at his/her hand using haptic displays of pressure, vibration, and temperature so that the human user feels the sensation that he/she is touching the object directly as he/she moves his/her hand controlling the avatar robot's hand. We can also synthesize virtual cutaneous sensation by displaying computer synthesized $p(t)$, $v(t)$, and $e(t)$ to human users through the haptic display.

This decomposition into pressure, vibration, and temperature in physical space is based on the human restriction of sensation in physiological space. Human skin has very limited receptors, as is the case in human retina. In the physiological space, cutaneous perception is created through a combination of nerve signals from several types of tactile receptors located below the surface of the skin. If we consider each activated haptic receptor as a sensory base, we should be able to express any given pattern of cutaneous sensation through the synthesis using these bases.

In particular, there are four tactile receptors known as the Merkel cells, Ruffini endings, Meissner corpuscles, and Pacinian corpuscles, which are known to be activated by pressure, tangential force, low-frequency vibration, and high-frequency vibration, respectively. By adding cold receptors (free nerve endings), warmth receptors (free nerve endings), and pain receptors (free nerve endings) to the four vibrotactile haptic sensory bases, we have seven sensory bases in physiological space. It is also possible to add the cochlea, to hear the sound associated with vibration, as one more basis. This is an auditory basis and can be considered as cross-modal. If we can selectively stimulate each of the seven receptors, we can produce any type of cutaneous sensation without having 'real' touching of an object.

3.2 TECHTILE Toolkit

There has been various haptic devices proposed so far, but most of them are still in emerging stage. To attract the interest of potential users of haptics such as designers, educators, and students, it is necessary to provide easy-to-make and easy-to-use haptic device.

TECHTILE Toolkit is an introductory haptic toolkit combining "TECHnology" with "tacTILE" perception/expression to disseminate the haptic technologies as the third media in the field of art, design, and education and extends the conventional "multi-media" which consists of visual information and auditory information. It composed of a haptic recorder (microphone), haptic reactors (small voice-coil actuators), and a signal amplifier that is optimized to present not only the zone of audibility (30-20000Hz) but also low frequency (less than 30Hz) vibrotactile sensation.

This toolkit is intuitive to use and can be developed with low cost, it can deliver even higher-realistic haptic sensation than many other conventional haptic devices. TECHTILE Toolkit uses conventional method on auditory media. The sources of auditory sensation and tactile sensation are the same. Vibration of an object generates a sequence of vibration of the air and perceived as sound, on the other hand, if the object were touched directly, it would be perceived as tactile sensation. The auditory sensation can be recorded as a sequence of sound waves, easily editable and finally share it on the Internet via services like YouTube or other content-sharing websites (Figure 9).

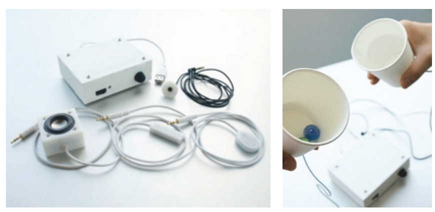

Figure 9: TECHTILE Toolkit

Throughout many workshops conducted in universities and science museums, we have confirmed that this device is suitable as an educational tool for learning possible applications of haptic design [2]. The attendees, aged from 6 to 50's, could easily understand how-to-use the toolkit in just 10 minutes. After that, they can create their original haptic artworks using their personal belongings such as papers, crayons, scissors, umbrellas, sandals and so on.

3.3 Haptic Editor

For the popularity of haptic technologies to reach the next stage, a creation system for haptic-enabled content is required. At present, the market offers a number of commercially available visual editors for creating and editing images or 3D models. Standard methods for the creation of visual content allow the user to copy and paste colors or visual textures from one place to another and even from real world to the virtual world. In addition, the render quality of current image editing has significant improvements with the help of photo realistic rendering.

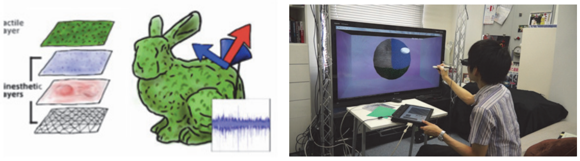

Figure 10: Haptic Editor

Haptic sensation represents integration of considerable amount of sensory information; therefore, it is difficult to design haptic enabled content. Although some research on 3D modeling systems using haptic interfaces has been conducted, these works do not focus on the creation of models designed for haptic interactions. To construct realistic haptic content, it is important to obtain detailed surface textures of real objects. There are a numbers of studies on surface shape reconstruction and some researchers have proposed devices for haptic scanning such as what that enables the user to obtain textures by interactively scanning the surfaces of objects. However, these methods reveal fine-grained surface details; they do not enable direct design or allow the user to test the sensations of touching the content.

Haptic Editor is a interactive content creation and editing system for haptic-enabled 3D content by drawing shapes in the air and copying and pasting surface textures. To achieve realistic haptic interaction, we define and create a data structure for haptic content using three kinesthetic layers and a tactile layer. To test the haptic sensations during the content creation, a pen-shaped haptic interface was developed (Figure 10). The user creates haptic 3D models by drawing geometries through aerial sketching; painting compliance and friction values on the layers; and copying and pasting the vibrotactile surface textures of real world objects to the surface of 3D content in the virtual world [3].

3.4 Repro3D

Most existing stereoscopic displays are based on the concept of binocular stereo. A binocular-stereo-based display cannot render an accurate image with motion parallax and cannot create images that would provide different perspectives of the same image from multiple points of view.

Repro3D is a novel full-parallax autostereoscopic three-dimensional (3D) display system that is suitable for interactive 3D applications with haptic feedback. Repro3D enable the users to interact with a 3D image by means of intuitive movements. Our approach is based on the retro-reflective projection technology in which several images projected from a projector array are displayed on a retro-reflective screen. When viewers view the screen through a half mirror, they see a 3D image superimposed in real space without the aid of glasses. RePro3D has a sensor function that recognizes user input; therefore, it can support some interactive features such as manipulation of 3D objects. In addition, a wearable haptic device, which is a part of our system, provides the user with a sensation of having touched the 3D image (Figure 11).

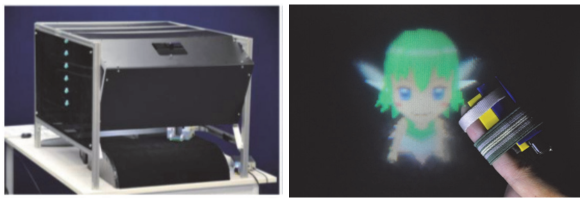

Figure 11: RePro3D

The array is integrated with an LCD, a half mirror, and a retro-reflector as a screen. An infrared camera senses user input. A number of images from the projector array are projected onto the retro-reflective screen. Our method can generate vertical and horizontal motion parallax. When a user looks at the screen through a half mirror, he or she, without the use of glasses, can view a 3D image that has motion parallax [4].

3.5 HaptoMIRAGE

HaptoMIRAGE is a visuo-haptic display that provides a wide-angle auto-stereoscopic 3D image on the content-adjustable haptic display so that it enables us to have an enchant interaction with the virtual world via tangible object with multi-modal sensation not only by one user but also by multi users.

Our aim is to implement a platform for storytelling, entertainment and creative collaboration by combining 3D vision and haptic sensation. Based on our active-shuttered real image autostereoscopic technology, we have developed a 3D image projection technology for multiusers that provides auto-stereoscopic real image in mid-air with a view of 180 degrees. We have also developed a content-adjustable haptic display based on the simple and realistic record & playback method, of which we can easily design the shape and the vibrotactile sensation according to the scenario of the content.

The 180 degrees autostereoscopic display consists of three components; each component has 60 degrees field of view, and provides an autostereoscopic image for one user. The Fresnel lens makes the real image from the LCD display, and the position of the user is measured by camera-based motion capture system, and the active shutter using transparent LCD panel provides the time-divided rays of the light for left-eye and right-eye. Then the user can see the real image as a floating 3D image. In this way the users up to three can see the autostereoscopic image from different viewpoints at the same time.

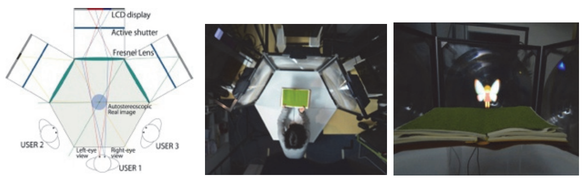

Figure 12: HaptoMIRAGE

The haptic display has multiple vibrators to provide spatially distributed haptic sensation to the user. In order that user can fabricate the form of the haptic display, we developed a creation method of haptic display using polymer clay and multiple vibrotactile actuators. The record and play-back method of haptic sensation is based on the method of TECHTILE toolkit and then the creator can design both the shape and applied sensation according to the content (Figure 12).

3.6 TELESAR V

Telepresence and Telexistence are technologies that allow a user to experience a sense of existence in teleoperations where the operator was provided with an immersive stereoscopic display, auditory feedback and the ability to move arms hands and head according to his/her postural changes. Teleoperations in daily life is helpful in visiting hazardous sites, remote surgery and sightseeing without spending much time on travelling, micro manipulation such as biotechnology, microsurgery, micro assembly and microchip manufacturing at nanometer scale, etc. The robots used in such technologies often have higher degrees of freedom to manipulate specialized tools with precision. However these movements are moderated from human's natural movements, thus operator sometimes confuses about the movements without knowing their available body boundaries. Furthermore, these teleoperated robots require special training in order to understand the body boundaries when performing tasks.

TELESAR V (TELExistence Surrogate Anthropomorphic Robot) is a telexistence master-slave robot system that was developed to realize the concept of Telexistence [1, 5]. TELESAR V was designed and implemented with the development of a high speed, robust, full upper body, mechanically unconstrained master cockpit and 53 degrees of freedom (DOF) anthropomorphic slave robot. The system is able to provide an experience of one's own extended "Body Schema" which allows a human to keep an up-to-date representation of the positions of the different body parts in space. "Body Schema" can be used to understand the posture of remote body and perform actions with the awareness thinking that the remote body is your own. With the above experience, users can perform tasks dexterously and feel the robot's body as his own body through visual, auditory and haptic sensation and that's

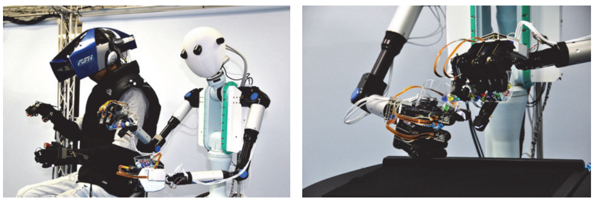

Figure 13: TELESAR V

the most simple and fundamental experience for feeling to be someone somewhere (Figure 13).

In July, 2012, it was successfully demonstrated that TELESAR V master-slave system can transmit fine haptic sensation such as texture and temperature of the material from an avatar robot's fingers to a human user's fingers [5, 6, 7].

The telexistence experience can be used not only with robots, but also allowing the new experience of controlling devices on personal space, games, next generation computing where users are not afraid of interacting with remote spaces and feel that what you see, hear, feel is real regardless of the provided stimuli. With the new experience, people will feel engaged in activities and the enjoyment that they will have might allow them to embed the remote space to their body.

4 CONCLUSION

This study is aimed at popularizing new haptic media and promote the evolution from visual and audio media to multimodal media. As television was the pinnacle of visual auditory information when it arrived on the scene, multimodal media can similarly be expected to result in a dramatic augmentation of the media industry. For example, information experiences based in reality will be obtainable through the advent of haptic product catalogs and advertising media, as well as the archiving of museum artifacts and skills of craftsmen. In addition, information errors due to inadequate resources conventionally only available to the visual auditory senses will be reduced, thereby achieving more effective information transmission. Furthermore, it can be expected that there will be a surge in the creation of haptic information content such as art that offers haptic experiences that do not actually exist. The effect of "haptic media" implemented in this study will not just be limited to creating a spur in the augmentation of the media industry. Experiences and creative tools associated with reality may resolve the dilution of the individual sense of existence in the contemporary society by stimulating human curiosity and increasing independence. It is exactly this heightened independence that creates an information environment in which "haptic media" is in harmony with humans, and as such, this study provides a maximal contribution to society. The popularization of "haptic media" constructed on the Internet may well take humanity to a new frontier consisting of a virtual environment associated with reality and embodiment.

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