4-2 3D Space-shared Communications
—Multimedia Virtual Laboratory Project—

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Since 1997, we have conducted the five-year plan called "Multimedia Virtual Laboratory Project," and the project has obtained the following results.

(1) 3D space-shared communication basic software, NetUNIVERS (Networked UNIfied Virtual Environment and Robotics Space). This software can merge 3D CG and 3D real images (stereo DV format) and share 3D space which consists of them among multiple points (up to 3 points with current version) over communications network.

(2) 3D geometric modeling, called "Extended Geometry Scheme" (Extended triangle geometry method). We succeeded in developing a unified, high-efficient and versatile geometric modeling scheme. This method is applied for part of NetUNIVERS.

(3) 3D display method without glasses, FLOATS (Fresnel Lens Optics And Two-image Stereoscopy). By using a convex lense (Fresnel), we developed a method that enables viewers to see the real images with high reality and without a feeling of wrongness. Usage of both parallax and focus functions of the eyes led this method to accomplish the reality and solidity of images.

(4) Ultra high-definition image processing technology with 8 million pixels (four times resolution as high-definition TV). We have developed a 3,840 by 2,048 pixel video projector and a CMOS-based moving image camera for the first time in the world.

Keywords
Computer Graphics, Geometric Modeling, Stereoscopic Display, Virtual Reality, Mixed Reality

1 Introduction

The history of human communications traces an evolutionary path from a voice-oriented stage (telephones, one-dimensional) to a primarily image-oriented stage (television, two-dimensional). We firmly believe that future communications systems will involve 3D space-shared communications (hereinafter, referred to as "3D communications"), that representations of 3D space itself will be transmitted and received. Such a communications scheme would allow virtual experiencing of remote points, much like the "anywhere portal" described in the Japanese comic series, "Doraemon."

The concept of 3D communications involves generating a 3D space and environment using 3D (solid) images and sound. This 3D information space/environment is shared among remote points over a broadband, high-speed network. We anticipate that such 3D communications will merge with Internet technology, and thereafter evolve into a next-generation Internet - what we call "Internet-3D."

In partnership with a number of research institutes, the Communications Research Laboratory (CRL) is promoting the Multimedia Virtual Laboratory Project (MVL), a research and development program dedicated to advanced multimedia technology. The CRL is currently conducting a five-year program that began in fiscal year 1997 that seeks to consolidate the partner research institutes into a single virtual laboratory center by connecting these institutes (remote points), which are widely dispersed across the country, with broadband networks. The resulting virtual center creates an advanced cooperative research and development environment.

Within this environment, the CRL has carried out various research and development activities on 3D space-shared communications as a core technology for the MVL. The CRL also seeks to create a collaborative communications environment offering a highly realistic presence, based on a 3D communications technology. In 1998, the CRL completed a 3D space-shared communications experiment facility, UNIVERS (UNIfied Virtual Environment and Robotics Space) (see Fig. 2(1), (2), (4)). It has been operational ever since. The UNIVERS is composed of three high-definition rear projectors, each with a 100-inch screen, a cluster of computers (Onyx2 graphics workstations and PCs), and telecommunications equipment, including MPEG codecs. The angles of the right and left screens of the three projectors can be adjusted relative to the middle screen, depending on the purpose of the experiment. In addition, the projectors are capable of stereoscopic display based on a liquid crystal shutter method.

As shown in Fig. 1, there are four major virtual reality facilities in Japan: CABIN[47] at the University of Tokyo, Co-CABIN at the University of Tsukuba, TEELeX at the National Institute of Multimedia Education at Makuhari, and COSMOS at the MVL Research Center in Gifu Prefecture. The UNIVERS is linked to these four facilities via the Japan Gigabit Network (JGN), a network dedicated to research and development of advanced network technologies and founded by the Ministry of Posts and Telecommunications (now the Ministry of Public Management, Home Affairs, Posts and Telecommunications). This network-based system functions as an advanced test bed of the MVL. This is called the MVL Gigabit Network. We are currently carrying out various MVL demonstration experiments in association with the MVL Conference (President: KUMAGAI Nobuaki, Professor Emeritus, Osaka University). Detailed descriptions of this study may be found in the Multimedia Virtual Laboratory demonstration experiments report [51].

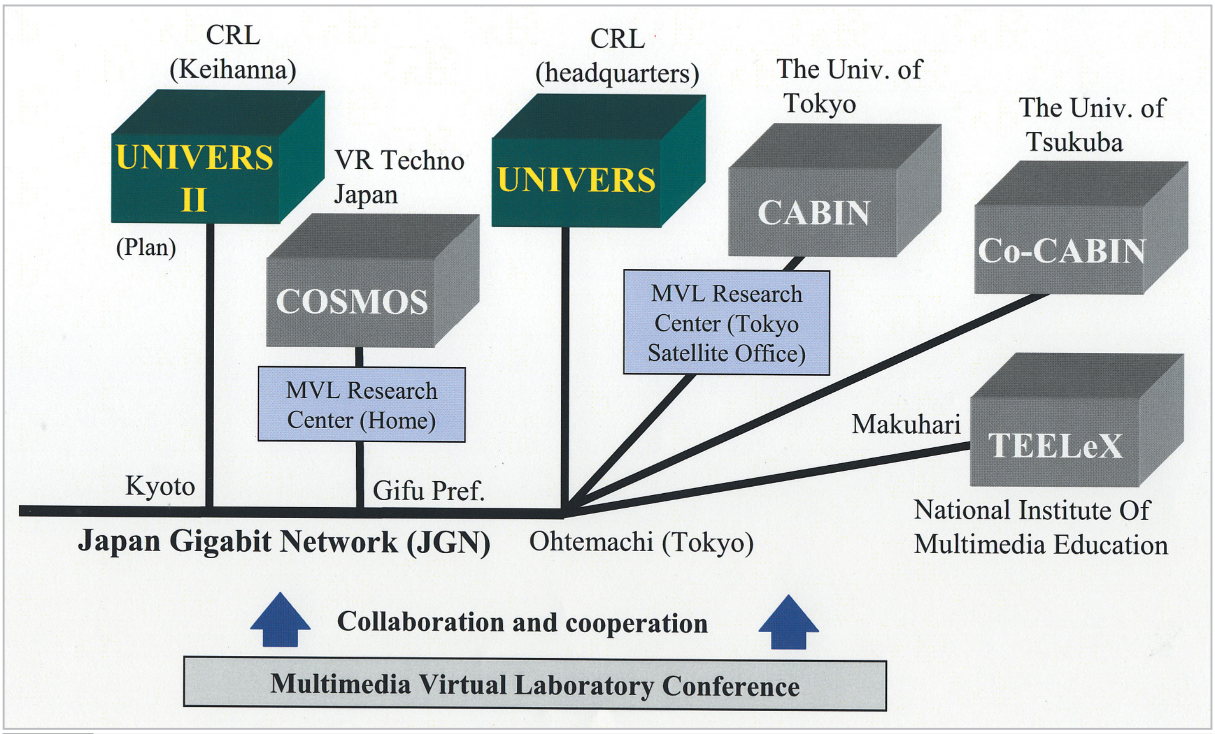


Fig.1 MVL Gigabit Network

2 Unified 3D information space

We believe that realizing 3D communications will require the unification of 3D information, including 3D computer graphics (CG), 3D real images, and 3D sound fields, and processing and communicating this unified 3D information space. More specifically, we have endeavored to establish a unified information theory (unified information encoding scheme) whereby CG and real images are represented using the same encoding method to facilitate unification, and thereby to process and communicate a unified 3D information space[15][16].

2.1 NetUNIVERS: 3D space-shared communications basic software

One of our research and development projects is called NetUNIVERS, an acronym for "Networked UNIfied Virtual Environment and Robotics Space." The NetUNIVERS is 3D space-shared communications basic software, a first step toward an actualization of a unified 3D information space (refer to Fig. 2). The NetUNIVERS software implements a 3D space in which the 3D CG and 3D real images (in stereo DV format) are merged. This space can then be shared among multiple points (up to three points with the current version) over an IP network. In the 3D space created over the network, CG and real image objects can be manipulated - that is, moved and rotated by teleoperations.

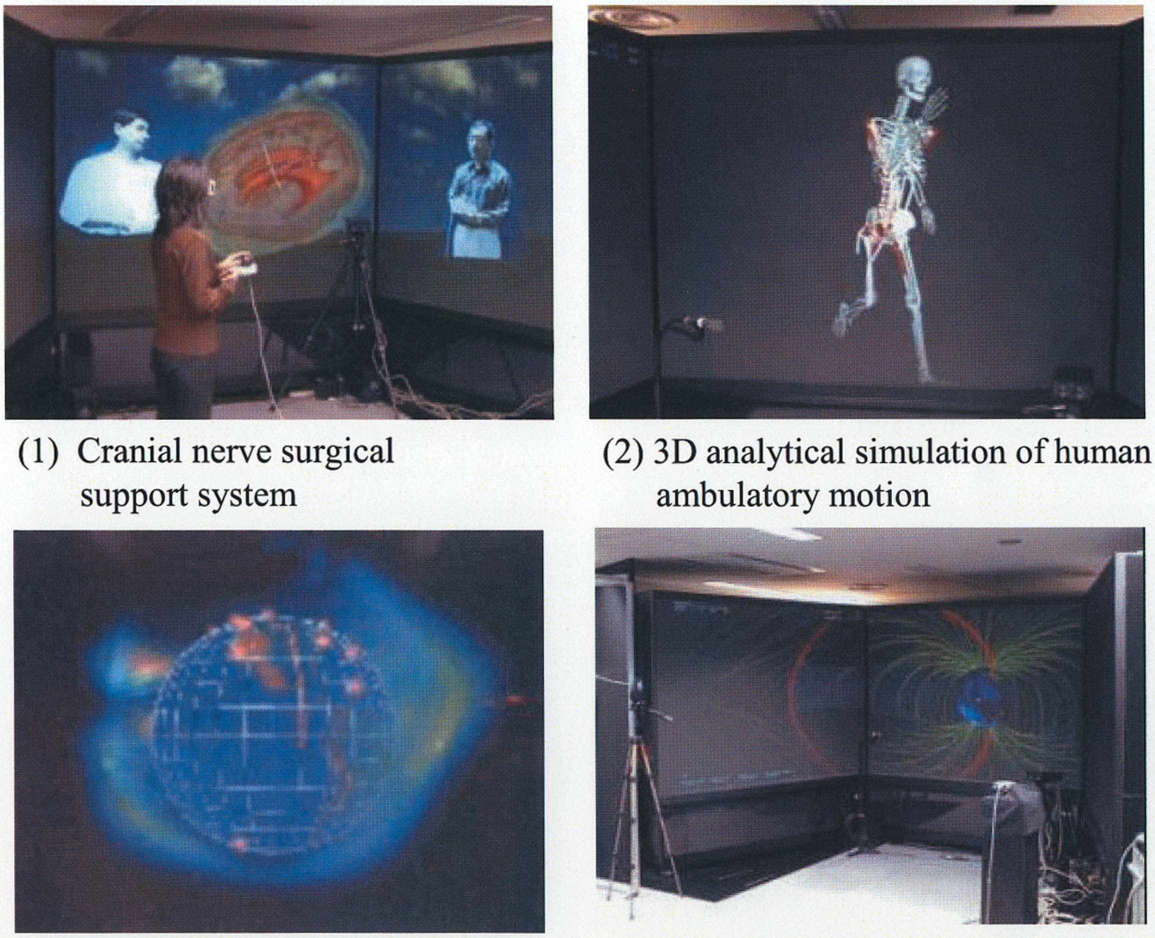
The standard system hardware consists of a single server PC to manage the CG and real image objects and to distribute real image data; PCs with 3D cameras at each of the three points, to capture stereoscopic DV-formatted images; and client PCs operating the three-screen display that outputs CG and image objects. Peripheral equipment includes 3D pointing devices, data gloves (each including a magnetic 3D position sensor), liquid crystal shutter glasses for stereoscopic vision, and audio codecs and devices that enable voice communications among the respective points.

The NetUNIVERS is based on an "Extended Geometry Scheme" (extended triangle modeling method), a CRL proprietary technology. This extended geometry scheme performs basic and essential geometric functions efficiently to carry out Boolean set operations (union, subtract, and intersect) between CG objects, which would take significantly longer by conventional methods. In certain cases, the large volume of data would, in practice, make such calculations impossible by conventional methods. In contrast, this new software makes it possible to perform geometric operations at high speed, with high precision. Compared to conventional software, the software achieves throughput on the order of several hundred times or better. The software can also check for interference between and generate cross-sections of CG objects.

For real images, the whole image, as is, can be sent to the other party, and part of the image can be cut out from the background using a finite difference method or a blue back curtain as a video avatar, to be displayed at an arbitrary position in 3D space. Based on this software, the following applications have been implemented as prototypes (see Fig. 2):

(1) Cranial nerve surgical support system
(2) 3D analytical simulation of human ambulatory motion
(3) 3D visualization of the upper atmosphere and the ionosphere
(4) 3D visualization of the geomagnetic field

The following is a report of communications experiments involving NetUNIVERS [50][51]. In an experiment carried out from October 29 through November 2, 2000, three sites - the CRL headquarters in Tokyo, the CRL Keihanna in Kyoto, and the National Institute of Multimedia Education at Makuhari - were linked by the JGN. The CRL headquarters used the UNIVERS system (consisting of three 100-inch screens), while the Keihanna Center used a single 70-inch screen. In an experiment carried out on March 12, 2001, three sites - Tokyo Medical University, a hospital attached to the Kurume University, and the CRL headquarters - were linked, and a basic communications experiment was under-



(1) Cranial nerve surgical support system

(2) 3D analytical simulation of human ambulatory motion

(3) 3D visualization of the upper atmosphere and ionosphere

(4) 3D visualization of the geomagnetic field

Fig.2 *3D space-shared communication software: NetUNIVERS*

taken.

The JGN was used as a backbone network. PVCs (Permanent Virtual Connections) were set up among the three points over an ATM network (OC3, 155 Mbps) as a fully-connected mesh network via ATM routers. Conventional IP 100BASE-TX was used as the communications protocol between the PCs. In each experiment, we verified that CG objects (CG models of the human brain) and real image objects (human body images) were successfully shared among the three points without visual incongruities, effectively securing a 3D image space.

2.2 Extended geometry scheme

In a first step toward the actualization of a unified 3D information space, we succeeded in developing an original unified geometric modeling method that we call “Extended Geometry Scheme” (extended triangle and extended tetrahedron geometry method - for which a basic patent has already been obtained). This scheme establishes a frame whereby all geometric models are represented and processed in a unified manner. This method also provides highly efficient and versatile 3D geometric modeling.

The real world and its apparent complexities are in fact composed of a certain limited number of atoms or elementary particles. Our perspective is that we can build an information world on the model of the real world, based on similar principles. Since the subject of our study is shape modeling, achieving such a geometric world consists of finding the primitive elements of shapes (geometric atoms). As shown in Fig. 3, we defined a point, a line, a triangle, and a tetrahedron as geometric atoms (or fundamental elements) that are not further divisible. Our research into 3D geometric modeling over many years has been based on this perspective. We have successfully constructed a unified geometric modeling system (unified CG space) that uses only these four geometric atoms as building blocks. That is, we have succeeded in developing a unified, highly efficient, and versatile 3D geometric modeling scheme, called the "Extended Geometry Scheme" (extended triangle and extended tetrahedron geometry method) [11]~[17]. The NetUNIVERS system was completed by further developing this extended geometry scheme of 3D space-shared communications software.

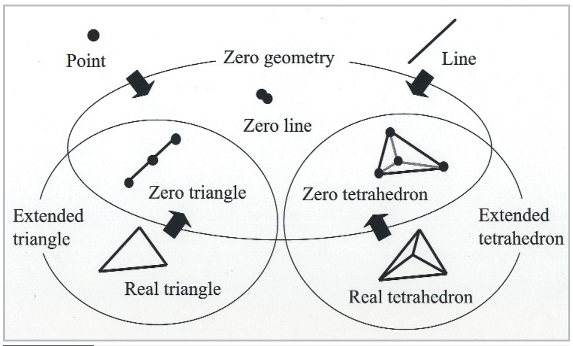


Fig.3 Extended Geometry Scheme and geometric atoms

The extended geometry scheme will be explained, using the extended triangle as an example. As shown in Fig. 4 (3), extended triangle representation extends the normal concept of the triangle and includes a degenerated triangle, whose three vertices are collinear. This degenerated triangle is called a "zero triangle," since its area is zero. Normal triangles are referred to as "real triangles." Both triangle types are generically referred to as "extended triangles." Extended tetrahedrons are similarly defined.

As shown in Fig. 4(1), conventional 3D geometric modeling (surface modeling) uses arbitrary polygonal surfaces, which require complicated processing algorithms and data structures, leading to poor processing efficiency. On the other hand, the triangle is a primitive geometric element that cannot be further subdivided. As shown in Fig. 4(2), using only the triangle allows us to achieve ultimately simple geometric representations. The drawback of this approach is that it also entails an exponential increase in the number of triangles as processing proceeds.

Using the above-mentioned extended triangle representation instead of conventional normal triangle representation allows us to significantly boost both representational capabilities and processing efficiency. The zero triangle offers both the properties of a triangle and a segment (amphibiousness). The zero triangle significantly suppresses triangle proliferation, while retaining the simplicity of triangle processing. For example, comparing Fig. 4(2) and (3), the conventional method requires 13 (normal) triangles to represent a surface. In contrast, the extended triangle method uses seven triangles, almost half the number required by the conventional method. Six additional zero triangles are excluded from triangle processing and treated as "segments." This makes it possible to realize high efficiency, high speed, and versatility for the 3D geometric modeling system.

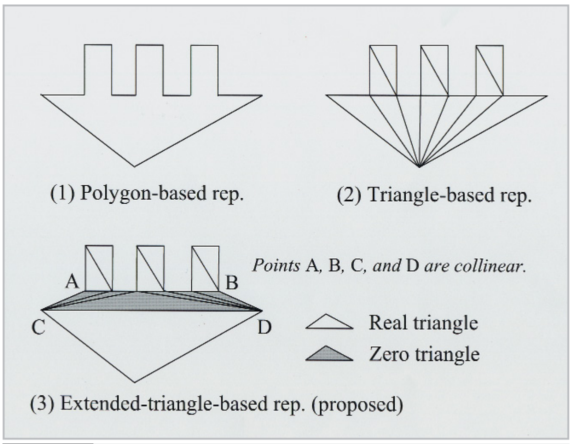


Fig.4 Extended-triangle-based representation

As shown in Fig. 5, during the process of dividing a triangular plane, the propagation of division toward surrounding triangular planes can be blocked with zero triangles, suppressing unnecessary triangle division. As shown by another example in Fig. 5, with conventional triangle processing, the process of joining two triangular surfaces requires division of the triangle; extended triangle processing does not. With extended triangle processing, the planes are easily joined, using no more than two zero triangles.

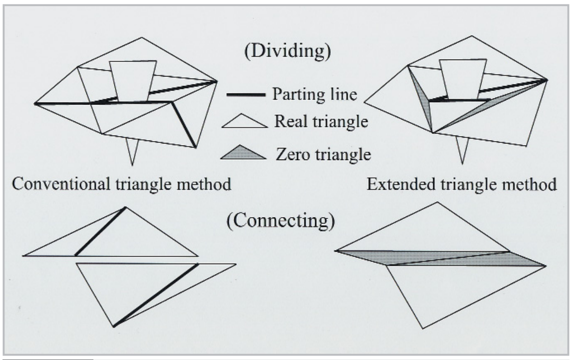


Fig.5 Extended triangle geometric processing

Creating a reality-enhanced 3D CG space requires the pursuit of various other aspects of visual representation, including computational simulation of the play of light upon objects. The radiosity method is a technique whereby a photo-realistic space is created by calculating the physical behavior of light (reflection, diffusion, mirror imaging, shadowing, etc.), based on a physics model running on a computer. Light from indirect light sources is also simulated.

Extended triangle geometry that is one of the extended geometry schemes was introduced into this radiosity method. A physical calculation model for diffusion and reflection with higher levels of rigor and accuracy than conventional methods creates a highly reality-enhanced 3D space superior to levels of realism conventionally attained (see Fig. 6). In the radiosity method, the division of a surface is repeated in mesh subdivision processing, as shown in Fig. 7. The extended-triangle-based algorithm was introduced into this mesh subdivision processing to suppress unnecessary divisions, thereby achieving high-speed processing that is several times faster than conventional methods (see Fig. 8). This research was undertaken in partnership with OptGraph, Inc[43].

(Courtesy of Optgraph, Inc)

Fig.6 Radiosity-based 3D space

(Courtesy of Optgraph, Inc)

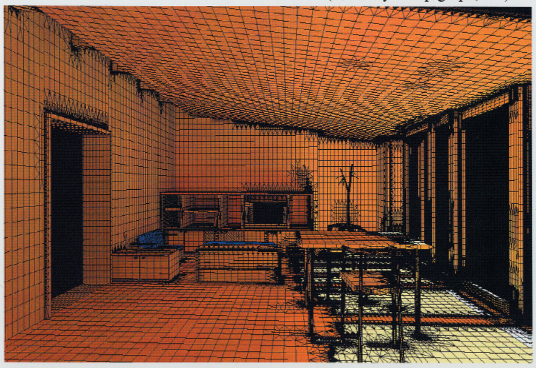


Fig.7 Mesh division

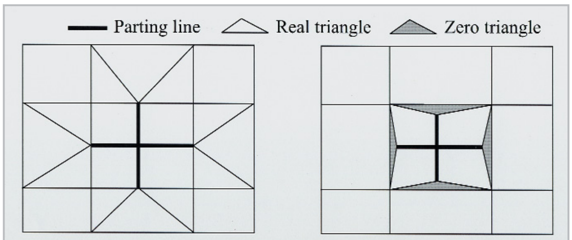


Fig.8 Mesh subdivision processing based on extended triangles

3 Robotics space

Truly realizing space-shared communications requires more than just providing an "intangible" space made up of images and sound. Another important aspect of 3D communications is actualizing a robotics space - a tangible space - wherein an operator can manipulate a space from a remote point using a haptic sensing device, a remote-controlled robot, and other devices[10]. Merging this robotics space with information space is another of our current research subjects.

One of the key requirements of a visual interface for such an operation space is that 3D images from the remote operation space be displayed as naturally as possible to the eyes of the operator, without visual incongruities.

With a conventional parallax-based stereoscopic display, the operator cannot recognize an image just in front of his or her eyes. This conventional system fails to give a perception of solidity to the operator, even when the display successfully presents the image before the eyes of the viewing operator. This is because with stereoscopic perception, the human eye uses information involving the focusing of the eye - particularly depth perception - in addition to parallax information (see Fig. 9).

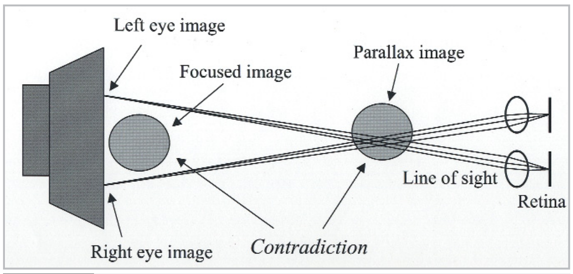


Fig.9 Stereoscopic display method based only on parallax

To resolve this problem, we developed a stereoscopic display method without glasses that is capable of providing a highly realistic and natural image, using both the parallax and focusing functions of the eyes simultaneously. As shown in Fig. 10, a convex lens (Fresnel lens) is interposed between the display and the viewer so that a real image of the screen of the display is formed between the lens and the viewer. We proposed a stereoscopic display method in which this real image formation and parallax presentation are combined (patent already obtained)[21]~[31]. This stereoscopic display system is called FLOATS (Fresnel Lens Optics and Two-image Stereoscopy). This system was presented, exhibited, and demonstrated at the international CG conference, SIGGRAPH2000 (New Orleans, USA, July 2000), as shown in Fig. 11[27][28].

To realize an advanced operation space that enables the operator to perform sophisticated operations, such as grasping an object, haptic sensations must be provided in addition to visual information. We have constructed a system in which SPIDAR[9], a haptic interface apparatus developed by SATO laboratory of the Tokyo Institute of Technology, is combined with our proprietary FLOATS. We are currently working to create a robotics space in which this system and the remote-controlled robot hand can be used together.

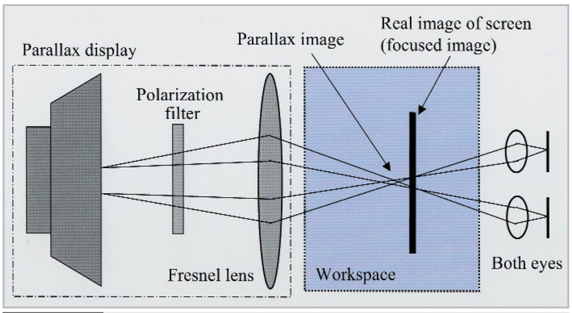


Fig.10 Stereoscopic display method that simultaneously uses both parallax and focus

Fig.11 Stereoscopic display method: FLOATS (demonstration scene in SIGGARAPH2000, held in July 2000 in New Orleans, USA)

4 Ultra high-definition image processing communications technology

In order to seek the highest degree of realism possible in 3D space-shared communications, we must establish an ultra high-definition image-processing communication technology. We have endeavored to establish an ultra high-definition image processing technology surpassing high-definition television (HDTV) and its transmission technologies. To date, we have achieved the following in research and development in the area of ultra high-definition image-related technologies.

4.1 Ultra high-definition video projector

Among potential ultra high-definition image display technologies that go beyond existing HDTV, the prevailing method is one that achieves ultra high-definition image display by arranging multiple display devices to perform parallel display (multi-screen method). Although this method can easily increase resolution in proportion to the number of display devices, it is difficult to remove the “seams” between the screens to create a seamless image.

To resolve this problem, we developed a projector capable of displaying an image having a resolution of 3,840 pixels wide by 2,048 pixels long (approximately 8 million pixels) upon a single screen (one picture plane), a world-first achievement. Shown in Fig. 12, this projector has no “seams,” for the highest image quality possible. This apparatus has a resolution approximately four times that of existing HDTV displays, which offer a resolution of 1,920 by 1,080 pixels.

High brightness, high definition, and high contrast were achieved for this ultra high-definition image display technology by combining a reflection-type liquid crystal display device - the Direct Image Light Amplifier (D-ILA), an advanced technology developed by the Victor Company of Japan - with a liquid crystal vertical orientation technique.

Fig.12 *3,840 by 2,048 pixels projector*

4.2 Ultra high-definition motion video camera

Although prototypes of motion video cameras with 4,000 by 2,000 pixel resolution have already been developed at some research institutes, these cameras are large and unwieldy, making them unsuitable for practical applications such as medical imaging and use at other image-shooting sites where ultra high-definition images are required. To develop an ultra high-definition motion video camera, we focused our efforts on the CMOS-based technology employed in digital still cameras. Finally, as shown in Fig. 13, we succeeded in developing a prototype of 3,840-by-2,048 pixel resolution ultra high-definition motion video camera that is as easy to use as a typical video camera. An image pickup device was the key to solving the problem. We have employed CMOS image pickup devices, due

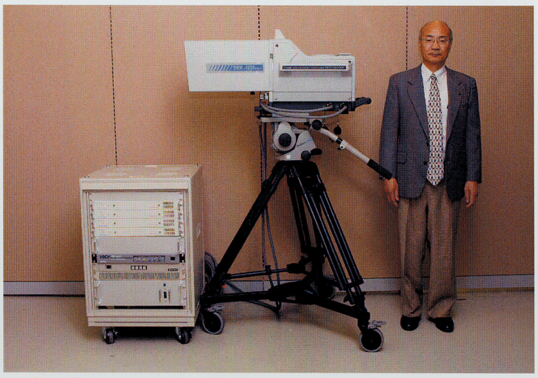


Fig.13 *3,840 by 2,048 pixels CMOS-based motion camera*

to their power-thrifty characteristics and suitability for mass production and miniaturization. At the moment, the quality of images captured by this prototype camera is inadequate, compared to CCD-based cameras, which are currently a mainstream technology. We are now adjusting and tuning the CMOS technology to resolve this problem.

4.3 Short-delay MPEG image encoding/decoding apparatus

MPEG2, a current standard coding scheme for HD (high vision) image transmission, comes with encoding overhead that results in time delays. Our developed apparatus reduces delay time to 180 msec, the best achieved anywhere in the world to date (Fig. 14). Selectable transmission rates include 22.5, 45, 60, and 120 Mbps.

4.4 Transmission experiment

The following communications experiments were conducted with these apparatuses [18][44]~[46][51]. In an experiment carried out on March 29, 2000, a soccer game between U-23 All Japan and U-23 All New Zealand was transmitted live. We connected the National Stadium of Japan in Shinjuku ward and the

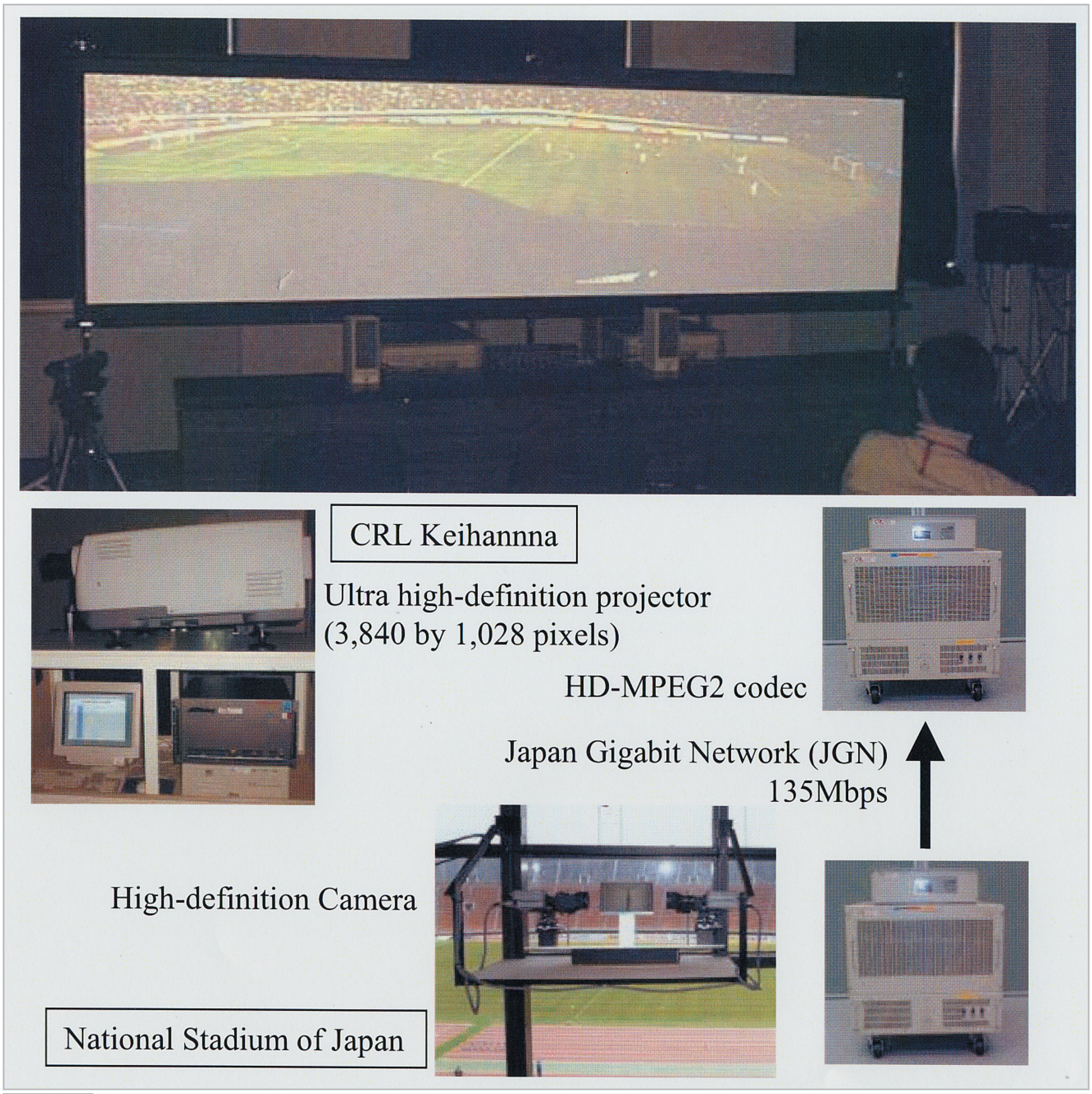


Fig.14 An ultra high-definition image transmission experiment on the first day of the 21st century

CRL in Tokyo via ATM 135 Mbps, dividing an image of 3,840 by 1,028 pixels into two HD images. We succeeded in carrying out real-time parallel transmission of motion picture data (live transmission) with two sets of the short-delay MPEG image transmission apparatuses (transmission rate: HD-MPEG2 45 Mbps × 2 = 90 Mbps). In this experiment, the entire pitch within the stadium was successfully displayed, with each player's number clearly visible. In another experiment performed on January 1, 2001 - the first day of the 21st century -we successfully transmitted 3,840 by 1,028 pixels images long-distance at even higher image quality, as shown in Fig. 14, by connecting the National Stadium of Japan and the CRL Keihanna (separated by approximately 500 km) with the JGN.

5 Future plan

In a nutshell, we believe that a next-generation information communications technology will require an evolution from multimedia to what we call "uni-media" (unified media). We may safely describe the current state of multimedia technologies as, in fact, a mosaic of media or low-level integration of media, requiring frequent conversion between media and various kinds of interaction. Like the human brain, uni-media is a high-level integration of multiple media. The human brain has various media receptors (five senses), which do not work separately, but are merged and unified in a highly sophisticated manner to function as a whole. While this account may not be precise from a physiological perspective, we certainly experience the five senses in an integrated manner, along a uniform continuum. We are convinced that a core area of future research will involve the actualization of just such a "virtual brain" - uni-media - on computer networks.

Our current uni-media research plan seeks to achieve a unification technology at the level of basic research. Robotics is another unification, rather than constituent, technology. One significant difference between uni-media and robotics is that the former involves unification based on information communications media, which includes the media of the latter, namely robots as constituent media. We plan to tackle the following specific research themes.

5.1 Integration and unification processing of 3D media

It is an essential part of our research plan to establish a hyper-dimensional information processing and communications technology, in which 3D information space-time consisting principally of 3D images, 3D CG, 3D acoustic fields, and 3D haptic sensation, for example, is represented and coded in a unified manner and structurally, and also unified and communicated.

5.2 Sophisticated processing technology of image media

Particularly for image media, realizing a sophisticated reality-enhanced 3D space that creates a sense of total immersion will require a completely 3D real image processing technology - in other words, a technology whereby visual information from the real world is captured three-dimensionally, without omissions, then processed, displayed, and communicated. We also plan to create an artificial visual perception (3D space recognition) mechanism based on this 3D technology. The resulting system will provide remote 3D vision and remote space perception and recognition.

Achieving an immersive 3D space also requires establishing an ultra high-definition image processing technology at levels exceeding the resolution of the human eye. Research on ultra high-definition image processing and display technology supporting 10,000-by-10,000 pixel-level resolution and related communications technologies is already underway. Such work will enable the creation of a sophisticated reality-enhanced 3D space-time. Research is also slated to begin on a whole body human interface based on ultra high-definition visualization.

5.3 Robotics space

We plan to construct a general-purpose 3D visual interface based on the highly reality-enhanced 3D display - FLOATS for remote operations that will enable the operator to perform operations just as if he or she inhabited the body of the remote-controlled robot. The research plan is to actualize a highly realistic 3D remote operation space in which the projected image and the operator are unified by deploying the FLOATS display at the operator's side, and by providing a multi-finger robot hand and a robot arm with physical forms corresponding to the human hand and arm and their respective functions at a remote location. This method will enable interactive action at a distance from the actual location of the operator.

5.4 Experimental test bed

The promotion of such research and development will require an advanced test bed to serve as its base. In the MVL, the MVL Gigabit Network test bed is based on links between major Japanese virtual reality facilities via the Japan Gigabit Network. We anticipate that the next stage in the development of this test bed, a more advanced version of UNIVERS called UNIVERS II, will be realized in the near future in the CRL Keihanna Human Info-Communications Research Center (see Fig. 2). This facility will be connected to existing facilities across a tera-bit class network, creating a test bed for research experiments on 3D communications and 3D media.

5.5 Internet-3D

The current pace of developments on network technologies promises the advent of tera/peta bit class networks sometime in the near future. Within a few short years, we can expect the appearance of optical computers and entirely optical communications switches. The arrival of such technologies will make it possible to realize the 3D space-shared communication described herein on a worldwide scale. We are optimistic that 3D communications over the Internet will become a reality in the near future.

It will be a natural extension of the technologies described here to create high-dimensional space-time-shared communications available at multiple points, on a global scale. In practical terms, we ask the reader to visualize a 3D Web with a high-quality 3D display and a humanoid-type robot, equipped with a remarkably intelligent 3D human interface. Our focus here is the pursuit of human-friendly interfaces that will make 3D space-shared communications available to all. This is our vision of the next-generation Internet - “Internet-3D” - an Internet based on 3D media. Our hope is that the 3D space-shared software NetUNIVERS described herein will become a *de facto* standard for Web browsers on the future Internet - Internet-3D.

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