

# ***Visual Interface***

## ***— Moving Toward the Future —***

September 11(Mon), 2006  
Arcadia Ichigaya  
4-2-25 Kudan-kita, Chiyoda-ku, Tokyo  
Japan



### **Sponsored by**

**IEEJ:**

The Institute of Electrical Engineers of Japan

**IEICE:**

The Institute of Electronics, Information and Communication Engineers

**ITE:**

The Institute of Image Information and Television Engineers

**HCECI:**

The Historical Committee of Electric, Communication and Information

**130th Committee on Optoelectronics** (Japan Society for the Promotion of Science)

### **Supported by:**

**JSPS:**

Japan Society for the Promotion of Science

**NICT:**

National Institute of Information and Communications Technology

# 映像インターフェースの未来へ

## *Visual Interface* — *Moving Toward the Future* —

2006年9月11日(月)  
September 11(Mon.), 2006

アルカディア市ヶ谷  
Arcadia Ichigaya  
東京都千代田区九段北 4-2-25  
4-2-25 Kudan-kita, Chiyoda-ku, Tokyo, Japan



### (主催)

**IEEJ** (International Exchange Grant) : 電気学会  
The Institute of Electrical Engineers of Japan

**IEICE** : 電子情報通信学会

The Institute of Electronics, Information and Communication Engineers

**ITE** : 映像情報メディア学会

The Institute of Image Information and Television Engineers

**HCECI** : 電気電子・情報関連技術史委員会

The Historical Committee of Electric, Communication and Information

**130th Committee on Optoelectronics** (Japan Society for the Promotion of Science)

: 日本学術振興会光エレクトロニクス第130委員会

### (協賛)

**Takayanagi Foundation for Electronics Science and Technology**

: 高柳記念電子科学技術振興財団

### (公的支援)

**JSPS** : 日本学術振興会

Japan Society for the Promotion of Science

**NICT** : 独立行政法人 情報通信研究機構

National Institute of Information and Communications Technology

# Welcome Address

To support the forthcoming “information society” for the next generation of people, who will probably obtain most of their information through electronic video, the electronic display technology (i.e., video interfaces) of the future is likely to become a highly important one with rich display capabilities and ultra fine detail, surpassing even that of works of art. Electronic display technology began with breakthroughs in television technology and subsequently took on the role of video interfaces as computers were developed. With the development of the Internet, it has come to play a crucial role in social activities as a video interface that allows people all over the world to gather and share information. Although much progress has been made, the telecommunications networks of the future will probably depend on functions that contribute to fostering a shared consciousness whereby people all over the world can share their local problems and work together for solutions and continued development. Hopefully, many developments and innovations will continue to be made in the future towards the implementation of user-friendly and richly featured video interfaces.

With this understanding and goal in mind, by welcoming the world’s authorities in these and other fields, we hope to reflect on the early breakthroughs in television that were made in Europe, the United States, and Japan, and to work on the future prospects of technologies aimed at video interfaces. It is said that new ideas can be developed based on study of the past, so by reviewing the origins of electronic television, we hope to develop stronger strategies for its future development.

We would like to thank everyone who agreed to contribute to this forum on the future of video interfaces, and we would like to thank everyone in the coordinating committee, for their considerable efforts in promoting and operating this forum. We would also like to acknowledge the event’s sponsors: the Japan Society for the Promotion of Science’s 130th Committee on Opto-electronics; the National Institute of Information and Communications Technology; the Institute of Image Information and Television Engineers; the Institute of Electrical Engineers of Japan; the Institute of Electronics, Information and Communication Engineers; all the members of the Electrical, Electronic and Information-related Technology History Committee; and the Takayanagi Foundation for Electronics Science and Technology for their help and cooperation.

September 11th, 2006



Yasuharu Suematsu  
General Chair



Kazumasa Enami  
Steering Committee Chair



# Program

## Welcome Address

### 9:30-10:00 Opening Ceremony

Steering Committee Chair : Kazumasa Enami (NHK)

#### Plenary Talk

General Chair : Yasuharu Suematsu (NII)

### 10:00-12:30 Invited Session

#### **Theme : Early Works of Video Display Research**

Session Chair : Eiju Matsumoto (SHMJ)

- Early Developments of European Television  
Oskar Blumtritt (Deutsches Museum)
- Early Works in Hamamatsu  
Hidenori Mimura (Shizuoka Univ.)
- A Visual Vision — 100 years and Counting —  
Joseph A. Flaherty (CBS)

### 12:30-13:30 Lunch

### 13:30-15:50 General Session

Session Chair : Haruo Okuda (Shonan Inst. of Technology)

- “Super Hi-Vision” future television  
Masayuki Sugawara (NHK)
- Visual Content Production and Digital Technology  
Mitsuru Kaneko (Tokyo Univ. of Technology)
- Free Viewpoint Television  
Masayuki Tanimoto (Nagoya Univ.)
- Color Reproduction in the Image and Video Display “ Beyond RGB ”  
Masahiro Yamaguchi (Tokyo Inst. of Technology)
- Electronic Paper : Display for Comfortable Reading  
Makoto Omodani (Tokai Univ.)

### 15:50-16:10 Coffee Break

### 16:10-18:30 Panel Discussion

#### **Theme : Visual Interface toward the Future**

Session Chair : Shinji Ozawa (Keio Univ.)

#### Panelist

Kenkichi Tanioka (NHK)  
Yuichi Matsushima (NICT)  
Minoru Etoh (NTT DoCoMo)  
Kazuo Okamura (Panasonic)  
Shunsuke Kobayashi (Tokyo Univ. of Science, Yamaguchi)

### 18:30- Reception

## Committee Member

# Plenary Talk

# *“Visual Interface: From the Beginning into the Future”*

Yasuharu Suematsu  
National Institute of Informatics  
2-1-2 Hitotsubashi, Chiyoda-ku,  
Tokyo, 101-8430

## **Introduction**

The development of telecommunications networks has made it possible to reach human beings anywhere in the world. Video display devices - in other words, video interfaces - are playing an increasingly key role in bridging the gap between networks and people. These interfaces are evolving in diverse ways, not only to assist in the acquisition and recognition of data archived in databases throughout the world, but also to offer human beings new ways to connect across large distances.

In this forum on the future of video interfaces, we will start by looking back at the breakthroughs in electronic video devices that occurred with the starting point of video interfaces: television technology. Next, we will review the current state-of-the-art video interface technology, which is currently being developed for video display devices such as computers and television receivers. We will then discuss how video interfaces are likely to develop in the future.

## **Television breakthroughs**

A long history of breakthroughs has accompanied the development of electronic technology for televisions, starting with the invention of the cathode ray tube by Karl Ferdinand Braun in 1897. This was followed in 1907 by Lee De Forest's invention of the triode, which made it possible to amplify electrical signals at high speed. The invention of electronic television systems required two breakthroughs: imaging technology and electronic display technology. The first televisions used a mechanical system developed by John Logie Baird (1925); this system was used for trial broadcasts in the following year. Analytical background was also shown by Herbert E. Ives. Meanwhile, trials and patent applications on the use of cathode ray tubes (the prototype of modern electronic television sets) as electronic display devices were conducted by researchers all over the world; these researchers included Vladimir K. Zworykin, Philo Farnsworth, Kenjiro Takayanagi, Alexander Douvillier, Max Dieckmann, Camille A. Sabbah, Charles Francis Jenkinns, Boris Rosing, Grabovsky, Reginald S. Clay, Robert C. Mathes, Frank Gray, Cambell Winton, et al. During this time, Takayanagi, who was an assistant professor at Hamamatsu Technical High School, had been conducting research on television and had been placed an ordered for a prototype cathode ray tube by his

won design with Toshiba Co. (1924). Takayanagi pointed out that mechanical television systems would only be capable of limited picture quality, and that it would be necessary to develop electronic systems that would be capable of overcoming this drawback. He claimed that he successfully displayed an electronic video image of a Japanese character called “i” on a cathode ray tube system (1926). It is said that Gray demonstrated a television system. And Farnsworth applied for a patent on an imaging tube and demonstrated the use of a cathode ray tube to display video images (1927). Zworykin had been made constantly breakthrough by Braun tube display and developing a excellent imaging tube. In this way, the development of television came about due to pioneering work by researchers in Europe, America, Japan, and elsewhere. Their efforts laid the foundations for the development of electronic television and electronic video display equipment. TV broadcasting eventually began in the 1930s.

### **From video display devices to video interfaces**

Computer technology underwent considerable development in the 1940s, and in 1950 the Whirlwind computer was developed at MIT. This computer incorporated a human interface based on a cathode ray tube. Further breakthroughs included the invention of the computer mouse connected to a computer display screen (1957) and Alan Kay’s work on personal computers (1970). As a result, electronic video display devices came to play an important role in interactions between humans and machines.

### **Solid-state technology and flat-panel displays**

The invention of the transistor (Bardeen, Brattain and Shockley; 1947) was followed by the development of large-scale integrated circuits (LSIs, 1958) and microprocessors (1972). As a result, electronic equipment became smaller in size, consumed less power, and became more reliable.

Progress was also made in the field of video tape recording (VTR), and significant progress was made in the scale of memory capacity based on the implementation of vertical magnetic recording and due to the development of technologies such as semiconductor memory, ferroelectric memory, atomic-force-probe memory, and large-scale buffer memory.

With the appearance of liquid crystal displays (Heilmeyer and Realte; 1968), compact and lightweight low-power panel display devices were incorporated into wristwatches and electric calculators, and later became widely used in portable television receivers and personal computers. Other display technologies have subsequently appeared, including plasma displays (PD), organic electroluminescent displays (OLED), field emission displays (FED), projection displays, and light-emitting diode displays (LED).

These technologies have made it possible to use electronic displays in a wide variety of applications.

Imaging devices have also become smaller and more stable due to the appearance of solid-state technologies such as charge-coupled devices or CCDs (Boyle and Smith; 1970) and high-speed complementary-metal-oxide-semiconductor devices or CMOS device. Solid-state imaging devices have made video capture devices much simpler and more durable. The field of photography has been revolutionized by the appearance of digital cameras based on this technology, which is now being used widely in mobile telephones.

### **Advent of super high definition TV**

Traditional National-Television-System-Committee (NTSC) standard and Phase-Alternation-Line (PAL) standard television pictures consisted of 500–600 scan lines. This was followed by the development of high definition television with 1,080 lines. Later advances in electronic display technology led to the development of Digital Cinema systems with 2,000 lines and Super High-Vision Television systems with 4,000 lines; the picture definition of the latter technology rivals that of printing technology and works of art. Progress has also been made in three-dimensional video technology, which allows the creation of three-dimensional virtual spaces, and efforts have been made to implement completely new virtual spaces in which human beings can interact with three-dimensional video objects. Unlike the traditional media of handwritten and printed material, this electronic video display technology has the potential to provide societies with new ways of working with information. The latest display technology, Super Hi-Vision, produces displays that surpass the quality of ordinary printed pages. Video display technology has also entered the domain of the expressive power of movie films, where it is used to display scenes in three dimensions (including the passage of time). The attraction of electronic video technology is in its ability to intertwine the video being projected with the people that are watching it, and there are many latent possibilities in the applications of four-dimensional virtual spaces depicting the real world. The spread of this sort of electronic display technology is likely to lead to the development of many new fields in the future. For example, it could be used in applications such as the four-dimensional design of assembly lines together with the flow of objects in a factory.

Super High-Vision displays, for example, also offer rich capabilities both in terms of presenting information and in terms of providing quality entertainment. Like the opera glass effect, users can individually view a large amount of information in the details of video content they are interested in by enlarging it either with eyeglasses or with an electronic eyeglass effect. In addition, this technology is expected to have a significant



effect on e-learning, and a wide range of fields by bringing such benefits as promoting the development of video-supported surgery, enhancing the performance of intelligent robots by increasing their field of view, and ensuring the safety of public streets by means of closed circuit cameras.

### **Future of network development and video displays**

The ARPANET network, which was started in the United States (1968), later developed into the Internet with the spread of personal computers in the 1980s. This globally extensive telecommunications network has been supported by the development of technology for communicating large volumes of traffic over large distances. Later, the growth of the World Wide Web from SERN (Tim Berners-Lee; 1989) gave rise to an era of information explosion by revolutionizing the functions for exchanging information and the means of sharing it between people in the world. Great advances were made in search engine technology, which grew into a giant business. Mobile telephones also underwent rapid development and became highly popular items, furthering the global spread of telecommunications networks.

In the world's telecommunications networks, video interfaces are widely used as core technologies that bridge the gap between humans and networks. The development of electronic video technology has been brought about through the combination of a wide range of fields in science and technology, including fundamental physics and chemistry, electronics, photonics, broadcasting, telecommunications network technology, and data storage technology. The driving force behind the technological breakthroughs and the growing popularity of ultra high definition large screen displays has been the necessity of making revolutionary developments in systems that can provide content with outstanding entertainment value, such as television broadcasts, and this is likely to remain the driving force in the future. In addition to making it possible for consumers to get high quality video in an economical way, these developments have brought spillover effects to other aspects of society, such as education and medicine. For telecommunication networks to fulfill their potential benefits to society, it is also essential to have functions that contribute to fostering a shared consciousness whereby people all over the world can share their local problems and work together for solutions and continued development. Video interfaces should continue to develop to achieve this important goal.

# Invited Session

# Early Developments of European Television

Oskar Blumtritt, *Member, IEEE*  
Deutsches Museum  
Museumsinsel 1, 81669 Muenchen, Germany  
o.blumtritt@deutsches-museum.de

## Abstract

*The early history of television technology has three different roots. First, as soon as the first telegraph systems came into being in the 1840ies some experts started with experiments in order to transmit facsimiles of texts and still images. Second, since the 1870ies mainly physicists investigated the relations between light and electricity and came up with some devices to convert light into electricity and vice versa. Third, the first patent for transmitting moving pictures was applied for in 1884, partly recurring on mechanic-optical traditions such as the fantascope and praxinoscope presented at fun-fairs.*

*But only after the establishment of sound broadcasting in industrialized countries around 1925, did the idea of developing broadcasting of moving images start to gain acceptance in engineering circles. At that time, well known electromechanical and optomechanical components were used in order to develop an effective television system. Despite the visions of cultural and economic values of an omnipresent, and even color television system, the technical development of the scanning, transmitting, and reproducing sets proceeded hesitantly. Different cultural and political orientations of the telecommunications industries, combined with different regulations of the telecommunications markets and with the competition amongst the industrialized nations, led to differences in their development strategies. These heterogeneous developments continued when it became obvious that mechanical components had to be substituted by electronic devices. Due to the political situation in the 1930ies, the establishment of a 'first regular television program' dominated the European scene, while in the USA the development of electronic components won the overhand. Especially the radar development, that is above all the dealing with very-high frequency systems, influenced the war and post-war technology of television.*

## 1. Introduction

Stories about television often start with the legend that a young German student of physics and mathematics sat alone in his little room in Berlin on Christmas eve in 1883. He yearned for his girl friend and thought about of how to communicate with her. Being acquainted with some knowledge of physiological optics and electrical physics, he planned to scan the flickering light of a candle by using a rotating disc with little holes in it. The light passing through these holes would be converted into an electric current which could be transmitted. On the receiving side the current had to be reconverted by a glow lamp into light of different intensity. A synchronously rotating disc would eventually reconstruct the image of the candle light on a screen. The young student, Paul Nipkow, successfully applied for a patent of his so-called electrical telescope on January 6, 1884. Nipkow never constructed such a telescope, and for the next forty years scarcely any scientist, engineer, or industrial manager was interested in developing sets or systems for transmitting moving pictures.

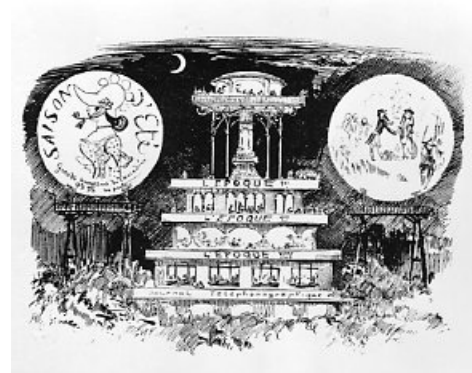


Figure 1: Advertisements and news on large screens, as suggested by Albert Robida in his book: *Le Vingtième Siècle*, 1883. (Deutsches Museum)

But writers, such as the prominent French science fiction author Albert Robida, had already depicted different scenes of how to apply television and picture telephony for communication, entertainment, and advertisement – without, of course, knowing Nipkow’s patent specification.

The path from an idea to its realization apparently is not the way in which the history of television technology can be approached. Instead, we have to concentrate on the intertwining developments of science and technology by integrating their economic, political, and cultural presuppositions and effects. Therefore, we have to investigate communications and media technologies as far as they paved the way to create systems able to scan, transmit, and reproduce moving pictures. Concomitant with this, we have to inquire as to which political/economical and cultural reasons forced or hindered the development of television. Moreover, we have to start with the establishment of the electric telegraph system in the 1840ies where the idea arose that it should be possible not only to transmit digital signs but also analogue images by means of electricity. But, as it is well-known, the electric telegraph, later accompanied by the electric teletypewriter, remained the most widely used communications means until the middle of the twentieth century when the telephone received a comparable acceptance. Fax machines developed into a widely used equipment only in the late 1970ies, due to an increasing demand in Japan and to the following international efforts in standardization. Picture telephones – as we recently could experience – were only accepted in the form of mobile phones.

As regards television, we can observe a different situation because of the overlapping developments in communications and – as we call it today – media technologies and their respective cultures. The initially unexpected rapid acceptance of sound broadcasting since the mid-1920ies led industrial and political circles to take into consideration that television broadcasting could produce added value. Although efforts in both communications and media technologies were genuinely oriented towards global enterprises, local, national, and international competition influenced the spread and the shape of television systems. The adaptation of different systems of color television in the 1960ies might serve as an example.

Tracing the early history of television in Europe – the central topic of this paper – has to reflect on both global and local aspects as well as on the tension between technical feasibilities and actual

establishments of television technologies and systems. In doing so, we will recur to technical and historical literature as well as to archival materials and artifacts which have survived. The Deutsches Museum has a large collection of television components and sets which can exemplarily serve as material sources and as means of illustration.

## 2. Some roots of image transmission in Europe

In 1844, the painter Samuel F. B. Morse finished the first public-use electric telegraph line between Baltimore and Washington in the USA. Despite various developments in other countries, especially in central and West-Europe, his telegraphy system would become the model from a technical point of view all over the world. One year earlier, in 1843, the Scottish clockmaker Alexander B. Bain, interested in applying electric phenomena to various technical fields, had suggested using his electrochemical telegraph also for the transmission of the characters of the alphabet. The raised parts of the characters could be mechanically scanned in lines and converted into electric impulses. Bain emphasizes in his patent specification that ‘telegraphed’ copies can be made from any image as long as it is constructed out of conductive and non-conductive segments.

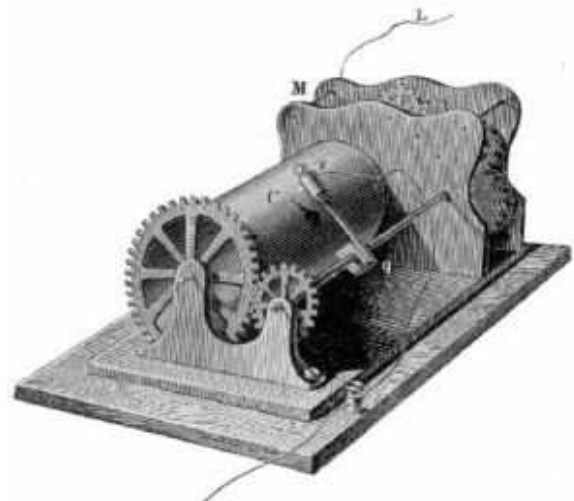


Figure 2: Bakewell’s picture telegraph as of 1849 – with tin-foil covered cylinder C, clock mechanism M, metal stylus T. (Deutsches Museum)

In the following years, several scientists and technicians, mostly from Great Britain, France, or Italy, tried to improve Bain's facsimile transmission. Some of them used metallic cylinders or plates whereby texts or line drawings were placed by a non-conductive ink on the transmitter side. Well-known were the apparatuses of the Scottish physicist Frederick C. Bakewell and of the Italian Abbé Giovanni Caselli. Although one could receive facsimiles over a distance of about 200 km in the early 1860ies there were economically unjustifiable restrictions due to mechanical components: the slow speed of scanning and the faults because of imperfect synchronization. As we shall see later, similar technical problems arose during the early development of television.

Although Caselli's 'pantograph' was used in several European countries and the French Post Office even installed lines for its public use in the late 1860ies, the public did not accept this quite expensive communications service. Therefore the French Post Office discontinued the service after a few years. One also has to take into account that both the professional and amateur photography was well established at that time and had influenced the public's visual perception. The digitally operating picture telegraphs, which could not transmit the graduations of gray tones in photographs, seemed to be unable to contribute to the often expressed needs for 'distant vision'.

The vision of 'distant vision' was enforced for a short time when the British telegraph expert Willbough Smith discovered in 1873 that the electric resistance of selenium could be influenced by exposing it to different light intensities. Smith was looking for a material of high electric resistance which he thought to have found in selenium. But it turned out that the behavior of selenium – an element known since 1818 – was unstable due to light effects. However, European and US-American scientists immediately became interested in investigating selenium because this topic fitted into the then widely discussed relationship of light and electricity. And most of them speculated about the use of selenium for converting light into electricity for distant-vision technologies. But material investigations of selenium in different physical states – from amorphous to crystalline – could not entirely overcome one characteristic of selenium, i.e. that the resistance only slowly returned to its initial value when the light source was removed. Nevertheless, physicists as well as technicians produced a great variety of selenium

cells and developed new schemes for transmitting still and moving pictures. Some of them suggested a mosaic of small selenium cells at the transmitter side whereby each of these cells were connected by a wire to a light emitting cell on the receiver side. To this group belonged the English physicist and telegraphy expert William Edward Ayrton, who had held a professorship at the Imperial College of Engineering in Tokyo in the mid-1870ies.

Although such circuits were in accordance with physiological investigations on the human optical nerve system and avoided the problem of synchronization, they caused difficulties in finding appropriate light-emissive elements and enormous costs in wiring. Others, beginning with the French lawyer Constantin-Louis Senlecq, preferred mechanical scanning systems, for instance with a selenium stylus. But the reproduction of the transmitted signals remained a problem here too. In this context the already mentioned efforts of Paul Nipkow from 1883, or of the French industrialist Lazare Weiller from 1889, can be seen. Weiller had transferred Nipkow's idea of synchronized rotating discs into synchronized rotating mirror wheels. Each of the mirrors on the perimeter of the wheel was deflected in a different angle in order to scan and reproduce the entire picture.

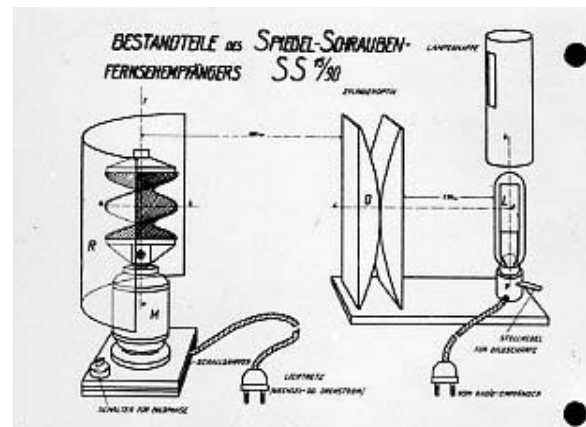


Figure 3: Mirror wheels were replaced by mirror screws (left) from 1927 on. (Deutsches Museum)

The list of names of individuals involved in the solution of detailed problems of distant-vision technologies in the second half of the 19<sup>th</sup> century could be enlarged to a great extent. Although many components were developed in laboratories nearly

none of the suggested television systems – as we would call them now – was really constructed and tested. Their inefficiencies were too obvious, not only on a technical but also on an economical level. Nevertheless, the culturally established visionary idea of distant vision, especially in the form of picture telephony after Alexander Graham Bell's telephone became worldwide known around 1880, continuously encouraged scientists and technicians to overcome some of the deficits that hindered a development on a large scale. This kind of modern thinking was legitimated by large sections of the population and supported by a development of the natural sciences, which easily related phenomena or effects found in the laboratory to devices which could be of technological use. The other way round, that is the scientific use of experiences made with technical devices and systems, proved to be effective in the same way. Along with this, there was an international exchange of scientific ideas, especially amongst the western nations. At this stage of the development of distant-vision technologies, the restrictions recurring to protection by patent were of minimal repercussion. The industries were not very enthusiastic about new communications technologies; but this implied also that they were not willing to sponsor these activities to a great extent – only as far as some of the components might have promised advantages in other technical fields, too. Finally, media technologies such as photography and cinema, which would become industrialized in the late 1890ies, were considered separate enterprises.

### 3. Aiming television systems

The term 'television' was coined by the Hungarian Constantin Perskyi in the title of his paper given at the International Electricity Congress in Paris in 1900. The German version of 'television', i.e. 'Fernsehen', already became known to the public via the book of Raphael Eduard Liesegang 'Beiträge zum Problem des elektrischen Fernsehens' in 1891. In these works nothing entirely new was said about television technology; but the authors summed up the state of the art in the late 19<sup>th</sup> century. In the first decade of the 20<sup>th</sup> century, the efforts to develop television systems changed insofar as they were accompanied by the establishment of a reliable picture-telegraph system, which allowed the transmission and reproduction of half-tone photographs. The picture telegraphy became widely used as a newspaper

service, and the public press envisaged the transmission of moving pictures as the next step in media technologies in the very near future. Nonetheless, scientists and electrical engineers were much more cautious in their predictions.

The English physicist Shelford Bidwell published a short article in the reputable scientific journal 'Nature' in 1908, where he presented his estimations on the requirement of receiving an image of 5.5 cm x 5.5 cm: One would need to transmit at least 150,000 image points ten times per second. The synchronization of these 1,500,000 operations and the respective frequency band needed could not be obtained by the means available at that time. The alternative, that is using several rows of sensitive selenium cells separately wired, would require about 120 line wires. Both systems, so his conclusion, would be highly impracticable – and extremely expensive. This statement, which was a response to the optimistic public press, shows on the one hand, that ideas of the technologies for television systems had not changed in the minds of popular writers. On the other hand, this kind of dealing with traditional ideas on television expressed the crucial problems of such systems more precisely than it could have been observed in the late 19<sup>th</sup> century. Therefore, mostly academically trained people who were interested in technical developments tried to convert physical instruments (or their knowledge of it) into technically usable devices. One of these instruments was the cathode-ray tube which would become a central part of television systems.



Fig. 1.

Figure 4: Scheme of the Braun tube in a physical journal, 1897. (Deutsches Museum)

The cathode-ray tube had its origins in the investigation of the effects of partly evacuated discharge tubes in the second half of the 19<sup>th</sup> century. One could find these kind of tubes in nearly all physical laboratories because they were regarded as a central instrument in researching the relationship, or the nature respectively, of negative and positive electricity, magnetism, polarization of molecules, and,

eventually, the construction of matter. Such experiments resulted, for instance, in the determination of the charge, mass, and velocity of the particles of cathode rays by the English physicist Joseph John Thomson in 1894. The concept of elementary charges, named electrons, was widely accepted since then, and led to a variety of new investigations of the discharge tube. The tube, which Thomson used, consisted of a long, closed glass tube. On the one end, a cathode and an anode provided the energy so that the cathode rays could travel through the tube. Guided by metal apertures and deflecting electrodes, the cathode ray could finally be made visible on a fluorescent screen on the other end. The German physicist Ferdinand Braun was able to develop this tube into a standard measuring instrument by slightly, but effectively varying some of its components. So the tube made its way from a specially designed physical device to a commercially produced instrument for various purposes. Braun was especially interested in measuring and visualizing alternating currents by avoiding the then used sluggish mechanical components. For that reason he widened the fluorescence screen of the tube, and instead of deflection plates he employed coils by applying their magnetic effect.

Jonathan Zenneck, an assistant of Braun, utilized a slightly varied form of this tube for his measurements of radio circuits from 1899 on. It soon became clear in scientists' and engineers' circles that the (nearly) inertia-free measuring instrument could be used for very high frequencies. The German physicists Max Dieckmann and Gustav Glage applied for a patent in 1906 in which they described a method of transmitting hand-written letters and line drawings by means of cathode-ray tubes. Whereas the so-called Braun tube (Braunsche Röhre) was used on the receiving side, the scanning was still done mechanically. One year later, the Russian physicist Boris Lvovich Rosing was the first to suggest integrating the tube as a receiver into a television system. He successfully applied for a German patent in 1908 and probably built his first television apparatus in 1911 – with the assistance of Vladimir Kosma Zvorykin.

Although most of the physicists and engineers were hesitant in developing television systems because of reasons mentioned above, it soon became common sense that inertia-free components at the scanning and reproducing side could at least solve some of the problems. This had already been true for the use of the so-called Kerr cell – invented by the

Scottish mathematician John Kerr in 1875 and applied in picture telegraphy since the late 1890ies. The Kerr cell could directly vary the intensity of light by being influenced in its polarization by electrical signals. And, of course, some suggestions and experiments were made to employ the (nearly) inertia-free Kerr cell in television receivers. As far as it is known, the first suggestion to produce an all-electronic television system was made by Alan Campbell Swinton in 1908. Campbell Swinton, a Scottish autodidact, enthusiastically experimented with all kinds of cathode-ray tubes, including x-ray tubes and Braun's oscilloscope tube, in his private laboratory since the mid-1890ies. The pessimistic article of Bidwell made him think about solutions of how to proceed in order to receive a practicable television system. In a letter to *Nature*, published there only two weeks after Bidwell's article, he stated that the development of the cathode-ray tube into a reliable receiver would not cause any serious problems. Two orthogonally placed coils should provide the varying deflection of the beam. A transmitter, with the receiver synchronized, had to be of the same construction. Here some difficulties might be encountered relating to the variation of the electrical current in harmony with the changes of the intensity of light and to the speed of this action, i.e. 160,000 variations per second in minimum. None of the known opto-electrical components would be able to perform such a rapid action, but he was confident that 'something' would be discovered in a not too distant future. However, his own efforts undertaken in this field over the next years with a Braun tube, which he had obtained from Germany, did not result in any decent solution for the construction of an electronic camera. But he soon came up with a suggestion of how a Braun tube might work as a camera: The image of a scene was to be projected through a lens on the screen of the tube where it would first traverse a metallic gauze screen, then pass through a gas, and finally meet a mosaic of photo-electrically active cubes consisting of metals such as rubidium. The cathode ray of the tube had to scan the backside of these metallic cubes. In the case that the cubes were illuminated, the cathode ray would pass through the ionized gas and meet the metallic gauze and be led to the receiver. Campbell Swinton proposed an image of 200 lines, the line scan being at a rate of 1,000 Hz and the frame scan at a rate of 10 Hz.

This far-sighted suggestion of an all-electronic television system was presented to the Röntgen Society (nowadays the British Institute of Radiology)

in 1911 and published in its journal one year later. But there did not exist any industry which would have been able to manage all the problems such as providing a sufficient vacuum technology, producing effectively working photoelectric cells, or supply the necessary transmission lines and amplifiers. The electrical industry, for instance, in nearly every industrialized country had just started to develop electronic components in the form of rectifying and amplifying tubes to be used in telephone and radiotelegraph circuits. Mass production of such electronic devices was established during the First World War. Some investigation in material research was done by the German teachers and scientific instrument makers Julius Elster and Hans Geitel from about 1890 to 1920. They came up with some new amalgams, such as of alkali elements, which led to the production of reliable photoelectric cells. Their work also provided a scientifically based photoelectric measurement. The German professor for technical physics, Arthur Rudolph Wehnelt, successfully improved the Braun tube during the first five years of the 20<sup>th</sup> century. Well known and widely used since then were the oxide coating of the cathode and the implementing of a negatively charged cylinder, the later so-called Wehnelt cylinder, around the cathode. This allowed lower voltages for operating the Braun tube and a quicker control of the cathode ray.

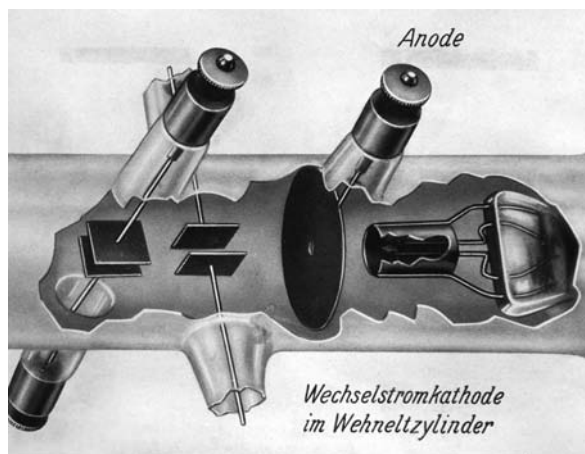


Figure 6: Wehnelt cylinder around the cathode (right).  
(Deutsches Museum)

Those and similar developments originated in a closely interwoven research in science and technology whereby the radio science and radio technology, as

well as the material sciences, belonged to the prime movers. During this process the physical sciences radically changed and, as it is well known, created new research fields such as the theory of relativity and the quantum theory. In communications technology, radio and telephony, including sub-domains such as high-frequency technology and filter design, became the preeminent branches in both research and economy. The vision of television still existed in the mind of the public and of some individual engineers and private inventors. They even got patents for suggesting technologies of color television, for instance. In industry, such kind of development and research was neither technically nor economically legitimated. The political control over technological developments, performed either by the military or by national Post Offices, also enforced the extension of traditional and the building of first of all reliable communications systems.

#### 4. Mechanical versus electronic television

In the 1920ies, the discrepancy between scientific and engineering circles on the one hand, and the public and private inventors on the other hand, continued insofar as a realization of television systems was concerned. Although some components and circuit designs now seemed to perform some features of image transmission better, some crucial problems still existed. So it is not surprising that mostly men, who were not closely attached to academia or industry, tried to develop television systems. One of the most prominent men in this field surely was the Scotsman John Logie Baird. Being a gifted tinkerer with elementary background in mechanical and electrical engineering and with some experience gained in an electrical power company, he tried to earn his money with inventions and the trade of unusual things – ranging from borax-sprinkled undersocks to ‘Speedy Cleaners’. Although he was not unsuccessful, he did not become a wealthy man, because his activities were often interrupted by long phases of illness. In the winter of 1922 he became interested in television by reading some visionary articles in specialist publications. He was wondering why no one had yet produced a television system, which seemed to be an easy task.

Baird’s first patent was filed in Great Britain in 1923. It describes the scanning with a Nipkow disc



and the reproducing of the image with an array of small incandescent lamps. The conversion of light into electricity was obtained by a common selenium cell and the transmitted electrical signals were distributed to the respective lamps by a metal arm rotating around a ring of contacts. This television set, operating with 18 lines and 20 frames per second, might just have produced very crude images. And it did not contain any new elements. But Baird managed to give a demonstration of his set to the press in early 1924. The following article in the Daily News about this first public demonstration of television brought him the first sponsor and some more interest from the public press, too. He now developed his system by using serrated Nipkow discs of up to 2,000 revolutions per second. Additionally, he surmounted the problem of the sluggishness of the selenium cell by providing circuits, which added to the output current of the cell the first differential of this current. Herewith he obtained electrical signals which were in their shape very close to those of the optical input signals. Further-on, the synchronism between transmitter and receiver was supported by a simple spindle with which the receiver could be tuned manually. Baird also mentioned the replacement of the selenium cell by a cell with a colloidal fluid, but he did not give any details. Nevertheless, there were still serious problems to overcome, such as the very poor signal-noise ratio.

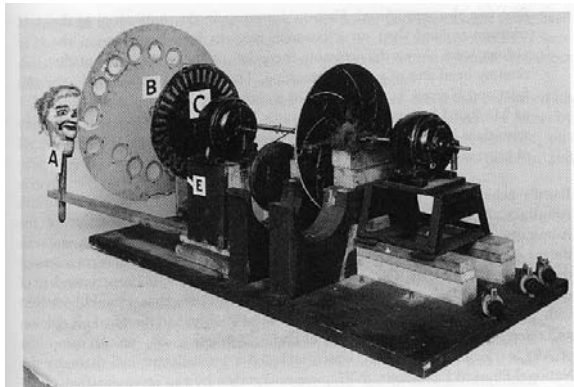


Figure 7: Baird's television apparatus, ca. 1925.  
(Science Museum)

To make it short, the technological and economical development in accordance with a steady public propaganda would continue in the same style until the 1930ies, i.e. even after the first company, the

Television Ltd., was founded by Baird together with associates in 1925. Baird did not try to hire renowned engineers or scientists; most of the technical work was done by himself and stayed on the level of mechanical television on both the transmitter and receiver side. Of course, the company tried to expand its networks nationally and internationally. Although the demonstrations of Baird's 'real' television were mostly appreciated by the press in other countries, too, the demand for his system with still crude images was not well received by the relevant circles in Great Britain and not accepted by most of the companies in other countries, which tried to compete with Baird's system. Especially, the British Broadcasting Corporation (BBC), which was converted into a non-private incorporation in 1927, did not show much interest in the poor performance of television until 1932. Only the British General Post Office provided some support by allowing the Television Ltd. to use its transmitter lines for several tests from 1928 on. This resulted, for instance, in the experience that it was of advantage to transmit image and sound on different frequency bands. In 1929, the BBC agreed to participate in just one of the tests, but at the expenses of the Television Ltd..

Although Baird's system laid down the basis for a reliable mechanical television broadcasting system in Great Britain in the mid 1930ies, the competition with other companies and the competition with electronic television systems – or just the use of some electronic components – led Baird and his company to lose their role as the prime mover in television. Further-on, Baird's many anticipations as regards the possible development of television – for instance, nightlight television, phonovision, two-way television, color television, and large-screen television – and his suggestions of how to solve the respective problems were successively regarded as ineffective sidelines. Others, such as the Hungarian mechanical engineer Dénes von Mihály, who had moved to Germany and was supported in his television work by the electrical company AEG-AG from 1924 on, came up with similar systems, but he concentrated on practical, reliable television transmission. All this indicates that television was increasingly seen as an earnest but not very profitable enterprise, especially in addition to sound broadcasting, in most of the industrialized countries at the end of the 1920ies. Half-heartedly supported by the management, renowned engineers such as the Swedish emigrant Ernst Frederik Alexanderson at General Electric in the United States, were engaged in varying components and circuits in

order to achieve a better control of light sources and synchronization. At another US-American company, the American Telephone and Telegraph Company (AT&T), a short but intensive research resulted in demonstrations of television from 1927 through 1930, that revealed both the maximum qualities and the limitations of mechanical television. The research was done in the famous Bell Laboratories, generously financed by their mother company.

The well-known limitations of the mechanical television systems encouraged some individuals to start with investigations in electronic television systems. Zvorykin, who had assisted Rosing – as already mentioned – with the development of a television receiver tube in 1911 and who had emigrated to the USA after the Russian Revolution, experimented on an electronic camera from 1923 on. While his initial ideas – although patented – did not work out in practice he was required by the research department of Westinghouse, where he was employed, to develop cathode-ray tubes for different purposes, including television. David Sarnoff, General Manager of the RCA (Radio Corporation of America) which was responsible for the research and marketing of radio equipment of General Electric and Westinghouse, eventually encouraged Zvorykin to concentrate on the development of his iconoscope which should become the most widely used television camera tube from the mid-1930s on. Others, such as the autodidact Philo Taylor Farnsworth in the USA or the engineering teacher Kenjiro Takayanagi in Japan, had devoted their life to an all-electronic television system. They came up with similar ideas and components; eventually, these three gifted inventors exchanged many of their ideas despite the industrial and national competition that was involved.

But coming back to the situation in Europe, one has to note that Zvorykin had been asked by Sarnoff to visit France before he could develop his iconoscope. This indicates that in France much work was done on improvements of the features of cathode-ray tubes, i.e. especially of oscilloscopes. All-electronic television in the narrow sense was not one of the primary research topics in Europe. To understand this situation, the development of Manfred von Ardenne's first so-called all-electronic television set shall serve as an example.



Figure 8: Zvorykin with his iconoscope. (Deutsches Museum)

## 5. All-electronic telecinema in Germany

In Germany, like in other European countries, the traditional communications industry was hesitant in investing in a research program oriented towards television systems. But the Imperial Post Office, regulating and operating the communication networks, showed interest in and supported such efforts already from 1927 on. It kept an eye on competitive developments, especially in Britain and the USA, and favored a practical mechanical television system rather than a visionary electronic one, which did not seem to be feasible in the near future. In 1929 the German Post Office and the German broadcasting authorities agreed on adopting a, at that time, rather low scanning standard: 30 horizontally scanned lines and 12.5 pictures per second; the aspect ratio being 3:4 (vertical/horizontal). The industry, dependent on the orders from the Post Office, had to keep this standard to a large degree. At the Berlin radio fair, the showcase of

the communications industry and the Post Office, the following mechanical television systems were on display in 1929: Karolus-Telefunken, Mihaly's Telehor, a joint project of R. Bosch AG, Radio-DS Loewe, and Zeiss Ikon (under the name of the just founded company Fernseh AG), an experimental set of the Post Office, and Baird's devices.

Siegmund Loewe, who ran a small radio company and held a share in the Fernseh AG, encouraged Manfred von Ardenne to think about electronic television in 1930. Ardenne, a gifted tinkerer and autodidact in physics and chemistry, had established a private laboratory for scientific electronic instruments and had made an accommodation with Loewe to produce devices in mutual interest because of his debts. His specialties at that time were oscilloscopes and even oscillographs as well as tubes and circuits for the entire new fields of ultra-high frequency and broadband amplification. So Loewe's demand did not seem a big challenge for him. Additionally, the production of 'electronic', i.e. 'inertia free', technical systems fitted the current ideology of progressiveness and modernity which the young Ardenne desired to be partaking in, due to his status as an outsider in science and (industrial) technology.

Ardenne had just to combine some of the components fabricated in his laboratory in order to achieve a set, which he thought would be a full-electronic television system. On the transmitter side a mains connection fed a cathode-ray tube which produced a small, bright light spot. The light went through a lens and a transparent slide and finally met a low-inertia photoelectric cell. The cell converted the intensity of the light into respective electrical signals, which were amplified by a broadband amplifier and transferred to the cathode-ray tube on the receiver side. Two saw-tooth generators were connected in parallel to the deflection plates of the two cathode-ray tubes. This provided synchronization as well as 25 images of 100 lines per second. Ardenne had oriented himself on the quality of cinema films which he saw in accordance with the physiological investigations in visual perception. Additionally, his television set allowed the electrical transmission of the then produced cinema movies at fairly high quality. Ardenne's ensemble met the high end of the unofficial television standard in engineering circles in 1931. The demonstrations of his set were internationally appreciated. It is interesting to learn from contemporary commentaries that emphasis was laid on the advantages first of the

receiver and afterwards of the transmitter, which became worldwide famous as 'flying spot scanner'.



Figure 9: Announcement of the presentation of Ardenne's flying spot scanner, 1931. (Deutsches Museum)

The images on the receiver side initially impressed television experts and authorities because of their brilliance, which was mostly due to the relatively high transmission standard used. The experts soon realized this and, animated by emphatic articles in the American press, they adopted the American term 'flying spot scanner' and praised the fully electronic transmission system for television purposes. Nevertheless, Ardenne did not reach his initial goal, i.e. to demonstrate that his system would have the potentiality to successively introduce better and better television standards. His system proved itself to be useful only for scanning movies, not for live shooting. The Zvorykin-type of camera tubes and, to a certain extent also the Farnsworth-type of tube, were introduced in Germany from the mid-1930s on. Both types used a storage process before scanning the image with the cathode ray and provided the potentiality for technological advancements and economical advantages. The scanning method of Ardenne was used for the transmission of movies until the 1980s.

While the German industry had to import television camera technologies it developed, on the one hand, mechanical television systems and, on the other hand, various procedures to improve the quality of television images, such as the line-jump scanning by Fritz Georg Schröter of the Telefunken company. Being aware of the fact that the European industry could not economically compete with the US-American companies, some European companies, especially in Great Britain and Germany, developed variations of Zvorykin's iconoscope and came up with the supericonoscope in 1934. In Germany, the intermediate-film process was introduced in 1932, i.e. live shooting with a movie camera, immediately developing the film, and scanning it electronically with a flying spot scanner or mechanically with Nipkow discs. The economical competition between companies on national and international levels was overlapped by political competition of nation-states. Germany and Great Britain mobilized their technical and structural resources in order to present the first regular public television program. Both states claimed to be the winner in 1935 but the smooth transition from test to regular transmissions let such statements seem absurd. While industries and Post Offices tried to push the development of television after 1935, in Germany, for instance, the ministry of propaganda pushed the cinema because of the technically better quality of the images. Although the production of an inexpensive receiver similar to the 'Volksempfänger' started in 1939, the Second World War stopped such undertakings. But the development of television was not stopped at all during the Second World War. Television became important for military devices such as guided missiles. Additionally, the research in radar technology enforced the research on higher and higher frequencies which in turn improved the quality of television transmissions.

## 6. Outlook

After the Second World War, all industrialized nations were able to establish public television systems in black and white and they did it successively in accordance with their economical and regulatory conditions. Whilst the USA had agreed on a 525-lines norm already in 1941, Germany introduced a norm of 625 lines in 1948 and France a norm of 819 lines in the same year. In 1951, international efforts were undertaken to standardize the global enterprise television, but they failed. Great

Britain even insisted on its low 405-lines norm. The same was true when the different color-television systems came into being (NTSC in the USA, 1954; SECAM in France, 1957; PAL in Germany, 1963). Summarily stated, Europe could hardly compete with the innovations coming from the USA. Video technology, stereo transmission, or satellite transmission in the 1950ies and 1960ies, respectively, may serve as examples. Another competition for Europe arose in Japan. Sony was the first company to equip receivers with transistors, and European countries oriented themselves towards Japanese efforts in video technology and high-definition transmission, for instance. Philips, a global player – as we would express it today – situated in the Netherlands, and which had introduced the new camera tube 'plumbicon' in 1965, was the only European company able to compete with America and Asia in the long run.

## REFERENCES

**Oskar Blumtritt** is senior curator at the Deutsches Museum, Munich, Germany. He is responsible for the telecommunications and microelectronics departments. His research covers the history of electrical science and technology.

- [1]. Abramson, Albert. *The History of Television, 1880 to 1941*. Jefferson, N.C. and London 1987.
- [2]. Blumtritt, Oskar. *The flying-spot scanner, Manfred von Ardenne and the telecinema. Presenting Pictures*. Ed. by Bernard Finn. London 2004, pp. 84-115.
- [3]. Burns, Russell W. *Television – an international history of the formative years*. London 1998.
- [4]. Chandler, Alfred D. *Inventing the Electronic Century – The Epic Story of the Consumer Electronics and Computer Industries*. New York etc. 2001.
- [5]. Fisher, David and Fisher, Marshall. *Tube – The Invention of Television*. Washington, D.C. 1966.
- [6]. Goebel, Gerhart. *Das Fernsehen in Deutschland bis 1945*. *Archiv für das Post- und Fernmeldewesen* 5 (1953), pp. 259-393.
- [7]. Hugill, Peter J. *Global Communications since 1844 – Geopolitics and Technology*. Baltimore, MA and London 1999.
- [8]. Takayanagi, Kenjiro. *Pioneering Television – The autobiography of Kenjiro Takayanagi*. Translated by Mayumi Yoshida. San Francisco, CA 1993.

# Early Works in Hamamatsu<sup>\*</sup>

Hidenori Mimura

Research Institute of Electronics Shizuoka University  
3-5-1 Johoku Hamamatsu 432-8011 Japan  
mimura@rie.shizuoka.ac.jp

## Abstract

Prof. Kenjiro Takayanagi joined Hamamatsu Technical College and commenced work on television in 1924. From the beginning he decided to work on an all-electric television system, using electron beams in both the transmitter and receiver. He devised the first television receiving Braun tube in 1925, however he failed to manufacture his design of pick-up tube because of poor vacuum technology. He compromised and decided to use a Nipkow disk in the transmitter. Following his inventions relating to television synchronization and deflection methods, it was on December 25, 1926 that he succeeded in reproducing Japanese character “イ”. The experiment was carried out using 40 scanning lines and a television picture rate of 14 per second, and it constituted the first success in electronic television in the world using a cathode ray tube (CRT). Prof. Takayanagi invented, in succession, a wide band amplifier, an accumulating system, and an electric interlace system. In 1935 he succeeded in manufacturing the iconoscope as an accumulating-type pick-up tube. At last he succeeded in reproducing highly detailed pictures, using 245 scanning lines, a television picture rate of 30 per second and a field rate of 60 per second. It was on February in 1936 that he accomplished the all-electric television system which he had initially envisaged.

## 1. Start of the Work on “All-electric Television System”

In May 1924 Prof. Kenjiro Takayanagi joined the Department of Electrical Engineering of Hamamatsu Technical College, (which later became the Faculty of Engineering, Shizuoka University) as an associate professor and commenced work on television with the understanding and assistance of President Sekiguchi of the College. He graduated from the Department of Electrical Engineering of Tokyo Technical College in April 1921. At the time of

graduation, Dr. Nakamura, who was the Dean of the Department of Electrical Engineering of Tokyo Technical College, gave graduates a discourse. The discourse stimulated him to devote himself to pursuing one important research theme for the next 10 to 20 years. At that time radio was on the eve of coming into home use, following the appearance of the wireless telephone. He did not choose radio as a research theme, and was excited by the consideration of how scenes could be reproduced at a great distance, in real time, from moment to moment. He coined the term “wireless distance electric vision” to describe what he envisaged at that time. One day he found a cartoon involving future television in a French electrical magazine, as shown in Fig. 1. In the cartoon, a screen mounted on a box like a radio set was drawn, with a girl singing on the screen. The cartoon was titled “Télévision”. He understood that, what he named “wireless distance electric vision”, was called “television” in France. He felt that television was already in the experimental stage, and he made up his mind to choose television as a theme to be pursued for the future. He had already heard the news that Baird was also working on television in Great Britain, Mihaly in Austria and Jenkins and other researchers in the U.S., but all their systems were mechanical. He racked his brains to determine in which direction he should proceed. At last he came to realize that the mechanical system of television was not suitable and would be extremely hard to realize, if a high definition image was to be pursued. It was in the autumn of 1924 that he decided to work on an all-electric television system instead of a mechanical one. When he made this decision, he had already envisaged the use of electron beams in both the transmitter and receiver.

## 2. Concept of the First Pick-up Tube and Failure in its Trial Manufacture

Prof. Takayanagi conducted investigations and

surveys concerning selenium and selenium cells, because the photo-conductive effect was well known in selenium cells. He acquired basic techniques for using thin selenium films, transparent metal films and electron beams. Making use of these techniques and materials he devised his first pick-up tube as shown in Fig. 2. This pick-up tube corresponds in its design concept to the modern vidicon. The first pick-up tube was manufactured in the laboratory of Hamamatsu Technical College, but his vacuum technology could not cope with this challenge.

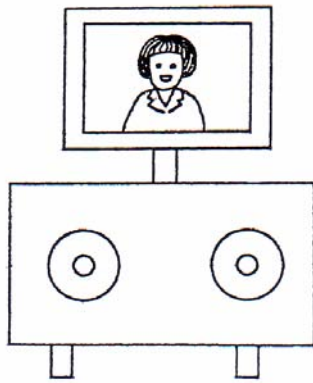


Fig. 1 Cartoon of the television of the future in a French electrical magazine (1923).

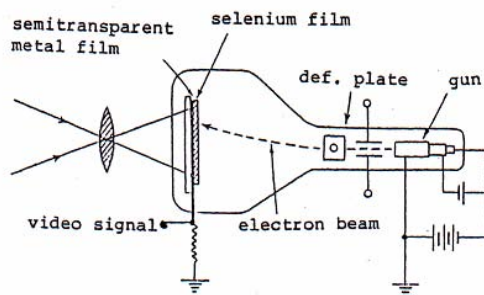


Fig. 2 First pick-up tube designed by Prof. Takayanagi (1924).

### 3. First Braun Tube

Prof. Takayanagi modified the Braun tube which was used in physical measurements and devised his first television receiving Braun tube as shown in Fig. 3. His first Braun tube featured (1) the use of thermal electron emission, (2) an electron flow control electrode, (3) horizontal and vertical deflection plates arranged in square to each other, and (4) gas focusing of the electron beam. Figure 3 shows a schematic of his first Braun tube, and a picture of the first trial Braun tube. This was manufactured in the autumn of 1925 with the cooperation of Dr. Asao at the Research Institute of Tokyo Shibaura Electric Co. (later Toshiba Electric Co). This was the first Braun tube of this shape in the world.

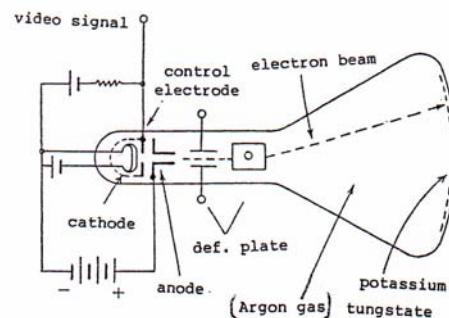


Fig.3 First television receiving Braun tube (1925).

### 4. Compromise System

The Braun tube was now at hand, but experiments on television could not proceed for want of the pick-up tube. To continue with his research, he decided to use the Nipkow disk in the transmitter until a suitable pick-up tube became available. He called this combination a compromise system. An experiment was successfully carried out, using 40 scanning lines and a television picture rate of 14 per second. His inventions relating to television synchronization



and deflection contributed to the success of the experiment. Figure 4 shows the operating principle of his invention. His idea consisted of automatic generation of horizontal and vertical deflection voltage with the correct waveform in the receiver and included the generating in the transmitter of a horizontal synchronizing pulse after each scan and a vertical synchronizing pulse after each sweep. These two pulses from the transmitter were sent to the receiver to synchronize the deflection generator. These synchronization and deflection methods still form the basis of the modern television receiving system. The Japanese character “イ” appeared on the screen using 40 scanning lines. It was on December 25 in 1926 that he achieved the first success in electronic television in the world, using a cathode ray tube (CRT). The picture of the Japanese character written on the mica plate of the transmitter is shown in Fig. 5.

In the years following this success, the transmitter was improved. By increasing the photosensitivity, success was achieved in the transmission of a human face or hands by early 1928. The pictures 6, 7, 8, and 9 show the transmitter, video signal amplifier, receiver, and received pictures, respectively.

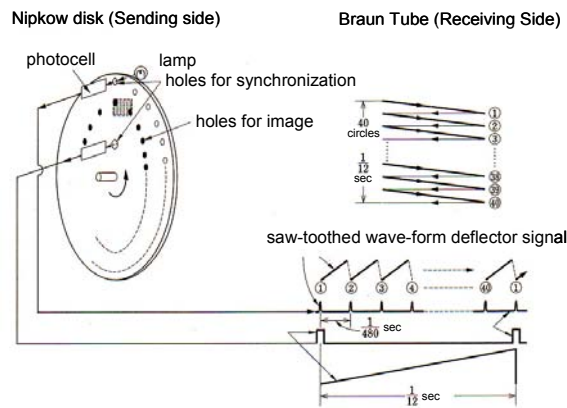


Fig. 4 Operating principle of the television synchronization method (1926).



Fig. 5 Picture of the Japanese character “イ” written on the mica plate of the transmitter (1926).

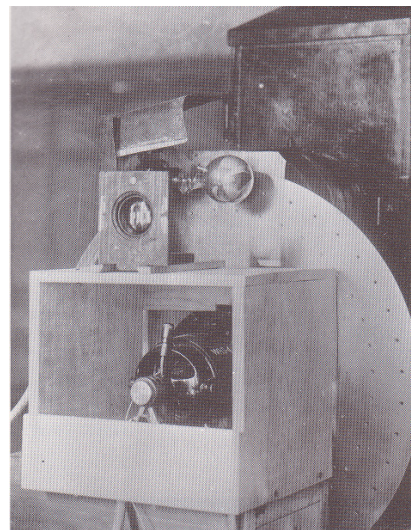


Fig. 6 Transmitter of the television system (1926-1927).

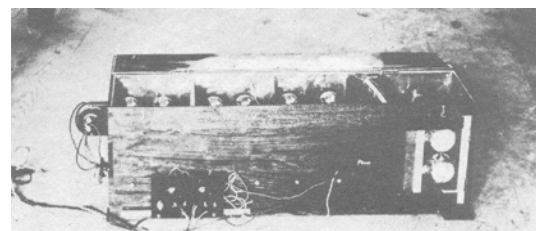


Fig. 7 Video signal amplifier of the television system (1926-1927).

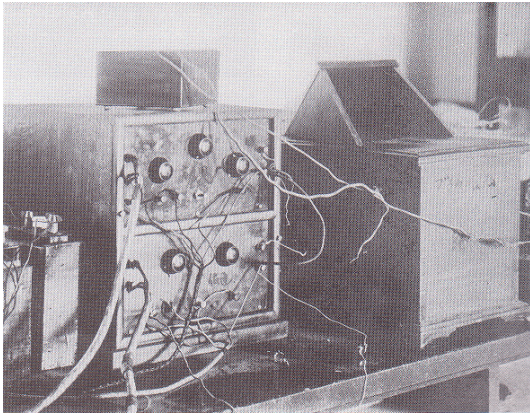
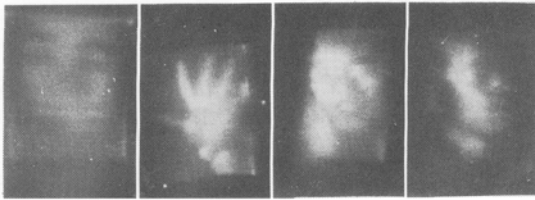


Fig. 8 Receiver of the television system (1926-1927).



(a)



(b)

Fig. 9 (a) Real pictures, and (b) images reproduced on the receiver (1926-1927).

## 5. Invention of the Television Braun Tube

To eliminate various defects of the gas filled Braun tube, Prof. Takayanagi invented a high-vacuum, multi-electrode Braun tube, as shown in Fig. 10. He asked Dr. Asao for cooperation in the trial manufacture of this high-vacuum, multi-electrode Braun tube. Trial Braun tubes were manufactured in two types with phosphor screen diameters of 15 cm and 30 cm. With this invention it became possible to increase the anode voltage from 240 V, used in the gas filled Braun tube, to 2,400 V at a stroke. This improvement produced a bright and distinct image.

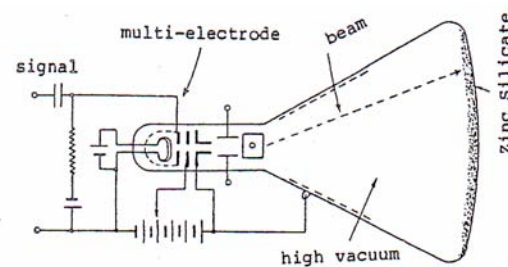
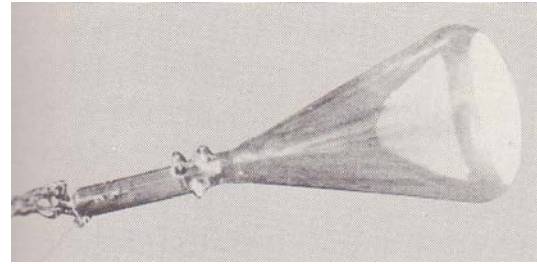


Fig. 10 High vacuum, multi-electrode Braun tube (1929).

## 6. Imperial Inspection of Television Demonstration

In May 1930 the Emperor visited Hamamatsu Technical College, and Prof. Takayanagi was honored with the Emperor's inspection of the demonstration of his television unit. Figure 11, 12, and 13 show pictures of the television receiving set, the received picture and the transmitter, respectively. After the demonstration to the Emperor, his electric television researches were recognized and significantly supported by NHK (Japan Broadcasting Corporation).

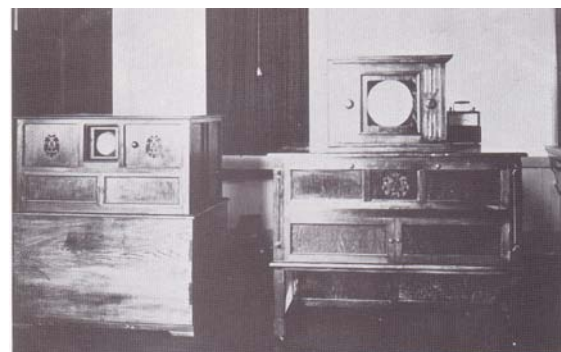


Fig. 11 Receivers of the television system. 15cm (left) and 30cm (right) Braun tubes (May 1930).





Fig. 12 Images reproduced on the receiver (May 1930).

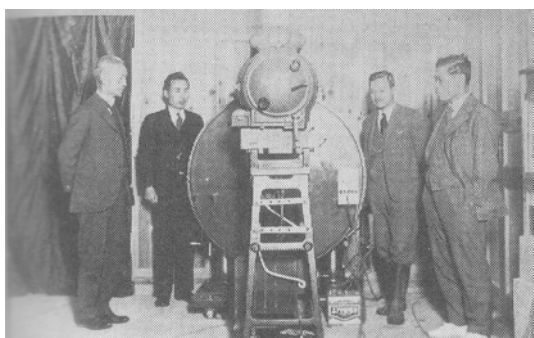


Fig. 13 Transmitter of the television system (1931).

## 7. Wide Band Amplifier

High definition television requires a wide band amplifier of the electrical signal derived from an optical image. In 1928, Prof. Takayanagi set to work on the wide band amplifier. After painstaking experiments and trial manufactures, a wide band amplifier was, at least, completed in 1930. In the course of experiments he came to appreciate that the stray capacitance, present in parallel with the anode resistance in the amplifier, attenuated the signal in the high frequency range. He reduced the stray effect and anode resistance to a minimum. As a result, a wide band amplifier that operated over an adequate frequency range was brought about, although the gain per stage was sacrificed to some extent. This wide band amplifier was tested in the television set which

operated at 100 scanning lines and 25 pictures per second. As a result, a vivid image, with fine detail, was reproduced by this equipment. He shouted "hurrray!" in spite of himself. The basic wide band amplifier circuit is shown in Fig. 14.

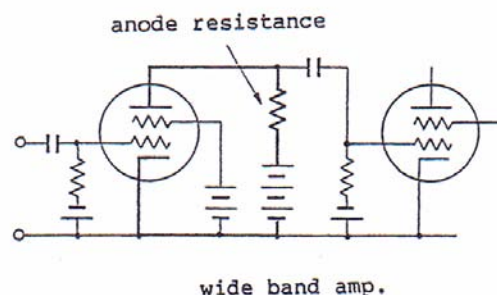


Fig. 14 Basic circuit of the wide band amplifier (1930).

## 8. Accomplishment of the all-electric television system

### 8-1 Invention of an Accumulating System

Great strides has been made in the research and development of the Braun tube and video amplifier so that it became possible to receive high definition pictures, but the problem with the transmitter could not be solved so long as the mechanical system, such as the Nipkow disk, was used in the transmitter. To solve this problem, Prof. Takayanagi resumed his work on the pick-up tube in 1930. He compared the human eye with the conventional transmitting system. As a result, he realized that, whereas the human eye received the total flux from the picture being sent at all times, the television system did not use the total flux from the picture, but only the flux from each picture element. Appreciating this concept, he devised an accumulating system that utilized the total flux from the picture at all times as in the human eye. The principle of the accumulating system is shown in Fig. 15.

### 8-2 Success in the Trial Manufacture of the Accumulating-type Pick-up Tube

Prof. Takayanagi heard the that Dr. V. K. Zworykin in RCA of the U.S. had invented the iconoscope and succeeded in producing highly detailed pictures from outdoor scenes by the use of the iconoscope. He visited Dr. Zworykin at RCA and saw the iconoscope in the summer of 1934. When he returned to Japan from his trip to the U.S., he and his research associates redoubled their efforts to develop the accumulating-type

pick-up tube. On October 10 in 1935 they succeeded in the trial manufacture of the accumulating-type pick-up tube, producing highly detailed pictures. Figure 16 shows a schematic and a picture of the iconoscope. Figure 17 shows the first reproduced image, obtained from the iconoscope camera. The experiment was carried out, using 220 scanning lines and a television picture rate of 20 per second.

To improve the picture quality, especially to eliminate flicker noise, Prof. Takayanagi invented the electrical interlaced scanning system. At last he succeeded in producing highly detailed pictures, as shown in Fig. 18, using 245 scanning lines, a television picture rate of 30 per second and a field rate of 60 per second. It was on February in 1936 that he accomplished the all-electric television system which he had envisaged from the beginning.

In August 1937, Prof. Takayanagi and his associates moved to the Technical Research Institute of NHK and undertook a variety of experiments in preparation for the television broadcasting of the Tokyo Olympic Games in 1940. In May 1939 an experimental television broadcasting station was set up in the Technical Research Institute of NHK. Test pictures were broadcast at 441 scanning lines and 25 pictures per second, using the interlaced scanning system. Prof. Takayanagi described in his manuscript that he felt proud of this experimental television broadcasting station which had been built and operated, solely by the Japanese.

\* The original of this article was written by K. Takayanagi on November 8th, 1981. The author (H. M.) revised the original manuscript by referring to the following:

- 1) K. Takayanagi, "Research and development of all electric television system", 1981. The original was own by the Foundation of the Promotion for Electronics in Hamamatsu (Hamamatsu Denshikougaku Syoreikai).
- 2) K. Takayanagi, "Terebi Kotohajime" in Japanese, 1981 Yuhikaku Publishing Co.
- 3) "History of the television technology in Hamamatsu" in Japanese, edited by the Foundation of the Promotion for Electronics in Hamamatsu (Hamamatsu Denshikougaku Syoreikai) 1987.

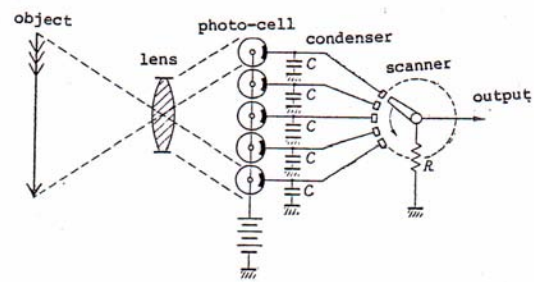


Fig. 15 Principle of the accumulating system.

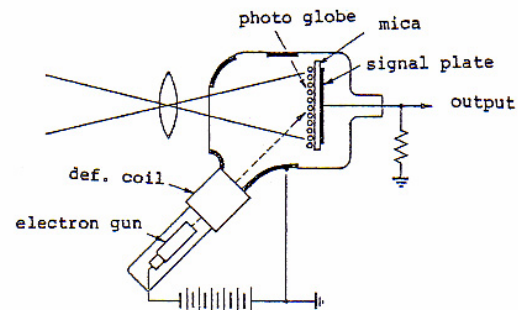


Fig. 16 Iconoscope manufactured in Hamamatsu Technical College (1935).

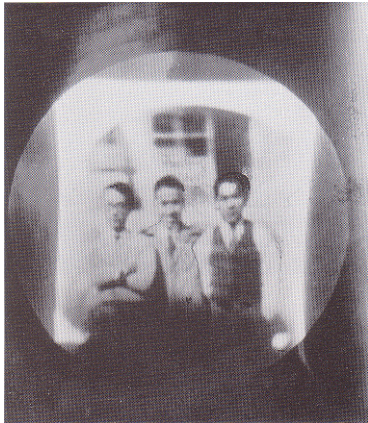


Fig. 17 First image reproduced from the iconoscope camera (1935).



Fig. 18 Image reproduced with all-electronic television system, 245 scanning lines, a television picture rate of 30 per second and a field rate of 60 per second (1936).



**A Visual Vision  
100 Years and Counting**

**Presented at**

**The Visual Interface Forum**

**in**

**Arcadia Ichigaya**

**Tokyo, Japan**

**By**

**Dr. J. A. Flaherty FIEEE FRTS**

**Senior Vice President Technology**

**CBS Broadcasting Inc.**

**Tokyo, Japan**

**September 11, 2006**

## **A Visual Vision**

### **100 Years and Counting**

A Visual Vision! Vision is the art of seeing that which will be, and vision and imagination are essential to all engineering and scientific enterprises. In 1936 David Sarnoff, then President of RCA said: “Progress in technology calls for imagination of the highest order and the courage to follow where that imagination leads.” Such vision, imagination, and courage brought television to its present state of excellence. Today, television is man’s window on his world, and, indeed, throughout the World more people watch television than are literate.

It all began with a vision over 100 years ago in 1875, before the advent of television developments, when Victorian cartoonist Robida foresaw the large, wide screen HDTV set in the English home. Figure 1 shows a Victorian family, in the comfort of their living room, watching a distant colonial war. Indeed Father is even equipped with a microphone with which he can shout interactive encouragement to the Imperial forces.

Today, television has become such a wide screen, high definition, and interactive reality as foreseen in 1875.

This reality began in 1911 when Campbell-Swinton proposed an all-electronic television system. By 1926 John Logie Baird introduced his Nipkow disc mechanical scanning system of 30 lines, Figure 2, and he called it high definition television. In 1927, H. E. Ives demonstrated a 50 line TV system, and so it all began.

At the same time, electronic television was beginning to emerge with the Audion triode tube, patented by Lee DeForest in 1907 enabling very weak signals to be amplified. Following this breakthrough in signal processing, Farnsworth introduced the image dissector, the first electronic camera tube in 1927, Figure 3.

Yet, not all foresaw the successful growth of television. A journalist in 1930 in a trade magazine entitled “Television” wrote:

“The over-enthusiastic televisionists are making their big mistake in thinking that television will repeat the glamorous history of radio broadcasting, when every sign indicates that it will not and cannot. Conditions are now altogether different from what they were ten years ago. Today we have a Federal Radio Commission, an aggravating patent situation, an over crowded ether, an overabundance of radio factories, a lot of politicians with radio axes to grind, and worst of all, a sophisticated buying element that has been spoiled by high quality radio broadcasting and high quality talking motion pictures.

If not for the ‘talkies’, the present crude televisors might stand a slight chance, as the mere novelty of a sight-and-sound combination would be enough to sell a lot of radio apparatus. However, the ‘talkies’ have entirely erased this possibility.”

Such doubters notwithstanding, television developments pushed on undisturbed!

The work of Zworykin in developing the all-electronic television system using the new kinescope enabled RCA to demonstrate a 120-line system in 1932 followed by NBC in 1934 with a 343-line television transmission demonstration. In 1936 the BBC introduced a 405-line service and called it HDTV.

By now, the high definition ball was beginning to roll with the introduction by Zworykin of the image iconoscope, Figure 4. Later the 1940 orthicon, and the 1946 image orthicon, Figure 5, with its great improvement in sensitivity and resolution it became widely used by broadcasters in the US and in Europe.

In 1950 Philips developed the photoconductivity based Vidicon tube and later the Plumbicon. Year-by-year, the continuum of technological advances increased the size of displays and the quality of the monochrome pictures.

The monochrome television world was doomed when CBS and RCA developed color television systems in the 1950s. When RCA developed a color kinescope or CRT, having a matrix of positioned red, blue and green colored phosphor dots combined with the RCA 525 line color television system, color TV was launched. This RCA system was standardized as the US NTSC color standard in 1953, and this standard has been firmly embedded as American color TV for 50 years; enabling the growth of the color TV set market to reach all the 109 million television households in the USA.

Thus, in 1935 high definition was 343 lines, in prewar England it became 405 lines, by the 1939 New York World's Fair it was 441 lines. In postwar America it became 525 lines and was colorized as NTSC in 1953. In latter day Europe it became 625 line PAL and SECAM color, and each of these quality steps was introduced as "high definition television".

Among most noteworthy modern developments were Video Tape by Ampex in 1956, the transistor, solid-state electronics, VLSI components, the VCR, the Trinitron display, and Electronic News Gathering (ENG) in 1972. Developments in digital video, digital image sensors, digital VTRs, and digital TV and HDTV enabled today's all-digital broadcasting.

Today digital technology dominates radio and television broadcasting, computers, the Internet and virtually all electronic systems. Analog broadcast equipment is being relegated to museums, and yet digital techniques in communications are not new. In fact, in 1623, Sir Francis Bacon, in his treatise: "The Dignity and Advancement of Learning", proposed to encode the alphabet by a binary communications system. He suggested that:

“Provided only that the matter included be five times less than that which includes it, without any condition or limitation, the alphabet can be resolved into two letters only, which by repetition and transposition through five places could represent all the other letters of the alphabet.”



With his five-bit "byte", he could compress and encode 32 different characters, or the letters of the alphabet, and he concluded:

"The contrivance shows a method of signifying and expressing one's mind to any distance by objects that are either audible or visible, provided only that the objects are but capable of two differences; e.g. fireworks, bells, or cannon."

Today it is two differences of ones and zeros, but hats off to Sir Francis Bacon.

In short, high definition has always been, and will always be, the best quality achievable with a given state-of-the-art. HDTV is always the best, not the second best, not the third best, and certainly not the previous best. Today, digital, wide screen HDTV has escalated television quality to a plateau never before imagined.

More importantly, there has never been a significant improvement in television technology that has not become a part of everyday American life, and HDTV is just the latest "must have" technology in viewers' homes, and so it will likely be in Europe and around the World.

The accelerating pace of television technology has not only served broadcasting, but has spawned a host of competitive delivery systems such as cable, direct-to-home satellite delivery systems (DTH), package video, VCR, DVD, TIVO, etc - many without the spectrum constraints of broadcasting. The broadcasters' monopoly of video channels to the home is gone, and gone forever. The television of abundance places broadcasters in an ever increasingly competitive environment.

So, as we evaluate tomorrow's digital TV and HDTV systems and plan for their implementation, we must bear in mind that today's standard of service enjoyed by the viewer will not be his level of expectation tomorrow. Good enough is no longer perfect, and may become wholly unsatisfactory. Quality is a moving target, both in programs and in technology. Our judgments as to the future must not be based on today's performance, or on minor improvements thereto.

Today television is 1920/1080/16:9 HDTV as first devised and developed in Japan, and introduced in North America by NHK and CBS on February 7, 1981. Figure 6 pictures the key participants in this first US demonstration of full HDTV, and includes motion picture director, Francis Ford Coppola and Dr. Takashi Fujio – a principal NHK developer of HDTV.

This HDTV system, with its common image format of two million pixels, was standardized by the International Telecommunications Union (ITU) in 1999, as Recommendation BT.709 and it became the single worldwide high definition production and program exchange standard. Without this ITU BT.709 high definition production and international program exchange Recommendation, the rapid growth of HDTV would

have been severely delayed and confused. Thus, without the ITU, there would be no BT.709 high definition Recommendation, and no global HDTV standard.

The International Telecommunications Union (ITU) is a vital link in the development and implementation of communications technology. Among the advantages of global ITU communication Recommendations are:

- Easier information transportability through the definition of interfaces and protocols among system elements, leading to interoperability and interconnectivity;
- Reduced costs for operators and users of broadcasting systems through economies of scale in capital and operating costs, including training and maintenance;
- Increased flexibility and functionality for users through user equipment and interfaces capable of operating across a number of broadcasting and other systems;
- Easier access of produced programs to the international market.

Following a host of HD tests and demonstrations in the 1980s, the FCC began a rulemaking process that would make DTV and HDTV the broadcast standard of the United States. The FCC Chairman, Alfred Sykes, launched the project in saying:

"I understand the concerns of those who believe in an incremental, step-by-step progression toward full HDTV, but pursuing Extended Definition options would tend to maximize transition costs for both industry and consumers. Stations presumably would need to make a series of sequential investments, as they inched toward full HDTV. At the same time, consumers almost certainly would be confused, and would probably resist buying equipment which, in relatively short order, might be rendered obsolete."..."The FCC cares enough about broadcasting and the service it provides the public to want the very best - full HDTV - and not some incremental solution to this formidable challenge."

America had a goal – full HDTV at the top of its visual hierarchy. Multi-step schemes "sneaking up" on HDTV as a final goal, were seen as unwise, a waste of time and money, and would do great disservice to the viewing public who would have to buy several versions of "enhanced" receiving equipment, and struggle through years of "evolution" on the way to real HDTV.

Darwinistic evolution had no place in HDTV! America would transition directly to HDTV in a single giant step.

The FCC, on Christmas Eve, December 24, 1996, approved the digital ATSC DTV and HDTV system as developed by the FCC Advisory Committee on Advanced Television Service (ACATS). The FCC decision allotted a second 6 MHz television channel to each analog TV station, but this spectrum was to be for the transmission of both digital SDTV and HDTV and was not limited to SDTV only. Thus, America future-proofed its digital HDTV transition.



The wisdom of this FCC dual SDTV and HDTV decision provided the maximum utilization of the limited broadcast television spectrum so vital to the very concept of terrestrial over-the-air broadcasting and, thus, future proofed American digital broadcasting

Spectrum, spectrum, spectrum; terrestrial broadcasting is all about spectrum, and America is now well supplied with the spectrum to support full HDTV broadcasting for every TV station in the Nation.

As of today, 1,566 of a total of 1,640 local television stations have completed the transition to DTV and HDTV transmission. 99.99% of the 109 million American television households in all 211 U.S. markets can receive at least one HDTV signal, and 91% of the TV households can receive five or more HDTV signals.

Four American TV networks, CBS, NBC, PBS, and UPN, broadcast all their scripted primetime entertainment programming and all major sports programming in full 1920/1080/16:9/24p and 60i high definition.

Two networks down-convert the 1920/1080/16:9/60i primetime entertainment programs to an intermediate quality of 1280/720/16:9/24p and 60p, a format with less than one million pixels.

Figure 7 shows the current CBS weekly HDTV broadcast schedule. These programs include all the scripted primetime evening entertainment programs, both the daily late night talk shows, a daily daytime serial drama, and virtually all major sporting events. All of them broadcast in full HDTV of 1920/1080/16:9/24p and 60i in accordance with the ITU-R Recommendation BT.709.

Figure 8 lists the live sporting events covered by CBS Sports with most in 1920/1080/60i HDTV. Many of these have been broadcast in HDTV for the last five years.

Including primetime, daytime, and late night programs, and sports, the broadcast networks produce over 7000 hours of original high definition programming per year. Moreover, such HDTV programs have an important after-broadcast sale in the expanding national and international HDTV syndication markets where SDTV “enhanced” program sales are fading.

The coverage of local ENG news in 1920/1080/60i HDTV is now growing rapidly. For example, this year CBS is converting 17 of its 35 owned TV stations to HDTV news with an initial purchase of 100 HD ENG cameras to be followed by 450 HD ENG cameras next year with all related editing and transmission equipment. A growing number of independent local stations and other networks are also making the transition to 1920/1080 HDTV news as SDTV news begins to vanish.

Cable systems are also moving heavily into HDTV. Today, there are 67 million cable subscribers in the USA, and the cable systems to which they are connected are equipped to carry high definition programming. These television households actually receive their

local terrestrial SDTV and HDTV television programs by cable. In these cable homes 70% of the viewing time is devoted to programming from the four major TV networks.

As shown in Figure 9, Cable TV subscribers in the USA can receive 1920/1080 HDTV programming from 35 cable channels that originate and distribute over 1,900 hours of high definition programming each week.

The two major satellite-to-home systems provide a total of 57 channels of 1920/1080 HD programming, and typically operate 20 hours per day, for a total of over 2000 hours of HDTV programming-per-week.

Taking broadcast, cable and satellite distribution together, and recognizing that not all cable channels listed are available to all consumers and that many programs distributed by satellite are also distributed by cable, the American viewer has over 2500 hours-per-week of high definition news, sports and entertainment programs available and this HDTV content is increasing at an accelerating rate.

Consumer electronics companies are also in synchronism with the growth of HDTV. With the plethora of HD programming becoming available, the consumer electronics industry has made great strides in expanding the consumer DTV and HDTV receiver market.

The annual unit sales of integrated HD receivers and the projections through 2009 are shown in Figure10. There were 9.8 million DTV/HDTV units sold in 2005 and 18.2 million sales are forecast in 2006.

It is forecast that the market penetration will rise to 26% in 2006, and to 83% by 2008 in final preparation for the 17 February 2009 shutdown of the NTSC analog service.

In short, consumer digital DTV receiver sales are booming, and among other things the boom is in HD receiver sales. This is due to the strong consumer appeal for 1920/1080 high definition quality, and to the steady drop in the sales prices of HD receivers, as shown in Figure 11.

Figure 12, shows that the revenue earned by consumer equipment manufacturers on the sale of DTV/HDTV receivers in 2005 was \$17 billion with a steady forecast growth through 2009 to \$33.2 billion, as the HD receiver market penetration nears 100%.

It is interesting to compare this DTV/HDTV growth with the corresponding decline in the sales of analog receivers, with the crossover point having taken place in 2003.

A similar pattern is seen in Figure13 with the growth of DTV/HDTV unit sales and the decline in the analog unit sales, the revenue crossover point occurring in 2006.

Another factor is the appeal of flat panel displays such that kinescope receivers are disappearing from the market. At the 2006 Consumer Electronics Show in Las Vegas,

there were over 100 flat panel HD models shown in sizes up to 102 inches with only few small screen CRT sets.

Television is HDTV, and HDTV is flat panel displays. Broadcasters and manufacturers, adapt!

Today HDTV is alive, well, and growing in Japan, the USA, Australia, Brazil, Canada, Mexico, and in many other nations. Standard Definition television, or SDTV, is rumbling on into oblivion and will be completely replaced by high definition.

However exciting this HDTV broadcasting rollout is, it is not the whole story. More competitive HD delivery systems are coming and coming fast!

The onset of the high definition DVDs in the BlueRay and HD-DVD formats will bring the viewer full 1920/1080 high definition quality, equal to, or better than, the best broadcast HDTV and far outclassing any digital SDTV or intermediate 1280/720p broadcasts.

Added to this DVD high definition competition is the recent announcement by both Sony and Microsoft that they are upgrading their new Play Station 3 and X-box 360 game systems to full 1920/1080 HDTV.

Keeping pace with this trend, the large full quality 1920/1080/60i&p flat screen displays now commercially available will sweep the HD consumer market and HD displays will no longer be low-pass filters as they have been until now. Finally, full HDTV can actually be seen, thus increasing the quality gap between full quality HDTV and all lesser formats!

In addition to the above, a growing number of programs are being distributed to the home or to mobile viewers through cellular telephony, pod-casting and by Internet streaming, thus adding to the total content distribution market, and tightening the terrestrial broadcasters' competition for viewers. Moreover, before long these new distribution media will also be able to transmit high definition content.

Further, we are at the threshold of even greater television developments in Large Screen Digital Imagery (LSDI) with its D-Cinema versions, and beyond these lie Extremely High Resolution Imagery systems (EHRI) at 3840/2160 with 8 million pixels and 7680/4320 with 33 million pixels.

The digital revolution is a momentous event in the history of our industry. As H.G. Wells put it:

“The past is but the beginning of a beginning, and all that is and has been, is but the twilight of the dawn.”

Such is the state of television art and science today. The tomorrows of television technology are now up to you. The Visual Visions of television's future rest with this new generation of scientists and engineers worldwide.

As these new engineers and scientists drive the inexorable march of visual technology, and the miracle of television quality throughout this 21<sup>st</sup> century, I commend you to the 1940 counsel of Dr. Alfred Goldsmith of RCA in his treatise on Engineering Ethics when he wrote:

“Engineering is a profession, not a trade. Engineers are members of an intellectual fellowship rather than of a competitive commercial group. As highly trained professionals over a long period of years, the knowledge of the past has been placed before us in carefully written textbooks, painstakingly prepared lectures, the facilities of universities, and the experience of great engineers and organizations. Our education, our lust for learning, and our dedication to excellence brings to us a high professional responsibility, a responsibility well beyond that of everyday trade and business disciplines.”

We, finally, need to treat television engineering as more than a business, or it will become nothing more than a business.

As you pursue this engineering responsibility in furthering the art and science of television in all its forms, remember in your work the observation of the philosopher Santayana:

“We must welcome the future, remembering that soon it will be the past, and we must respect the past, remembering that once it was all that was humanly possible.”

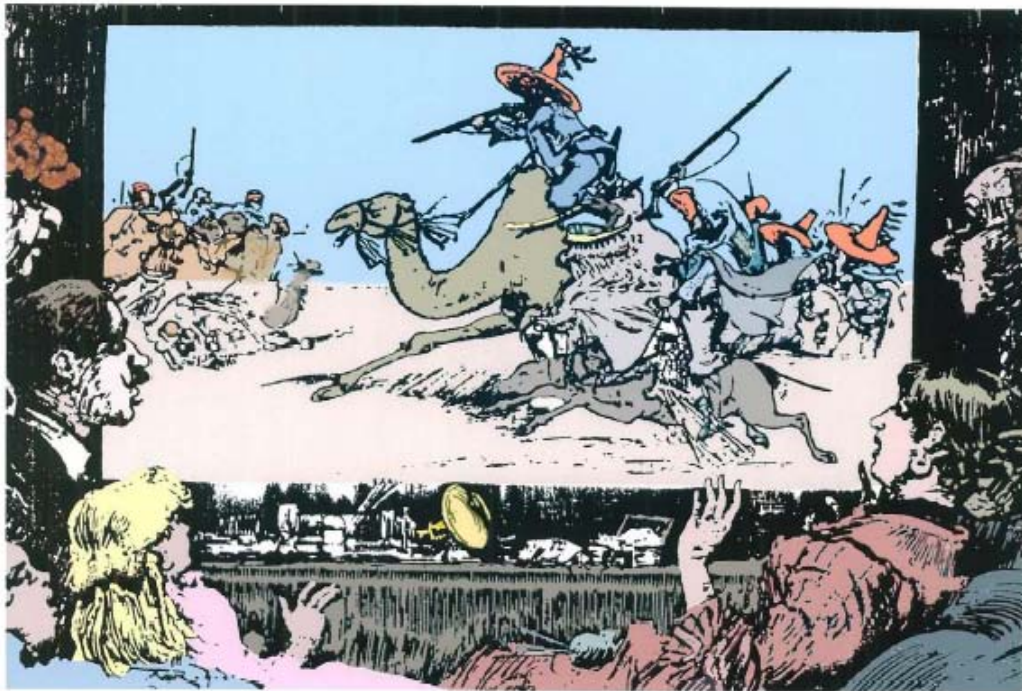


Figure 1

## The Nipkow Disk

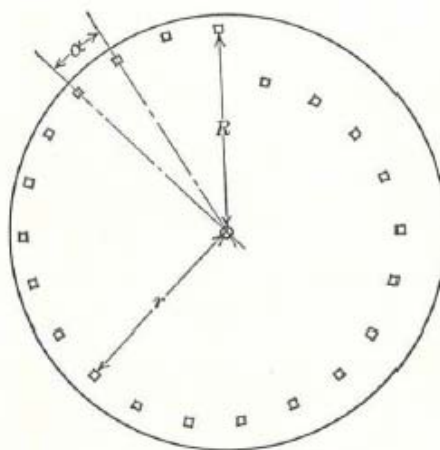


Figure 2

## Early Farnsworth Image Dissector Tube

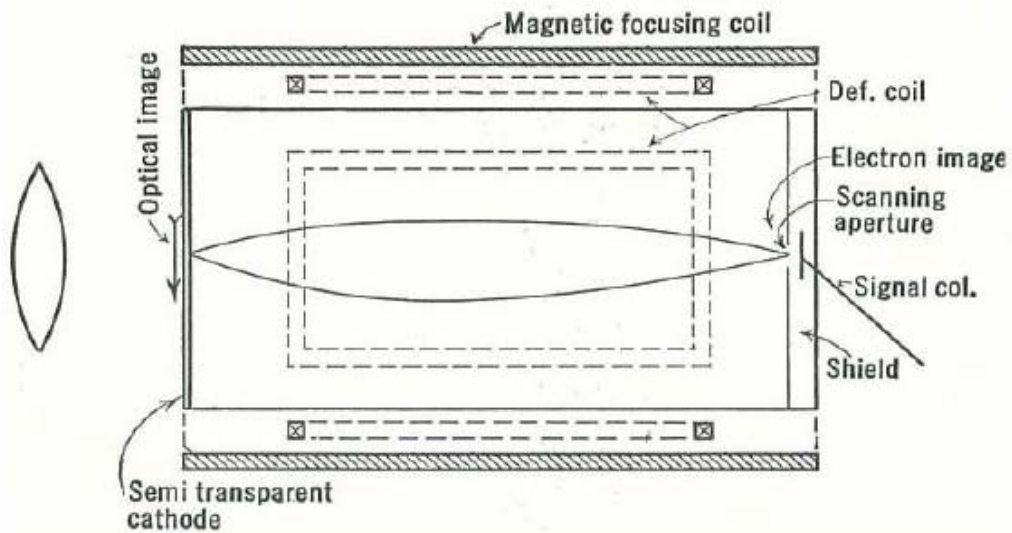


Figure 3

## Normal Iconoscope with Single Sided Mosaic

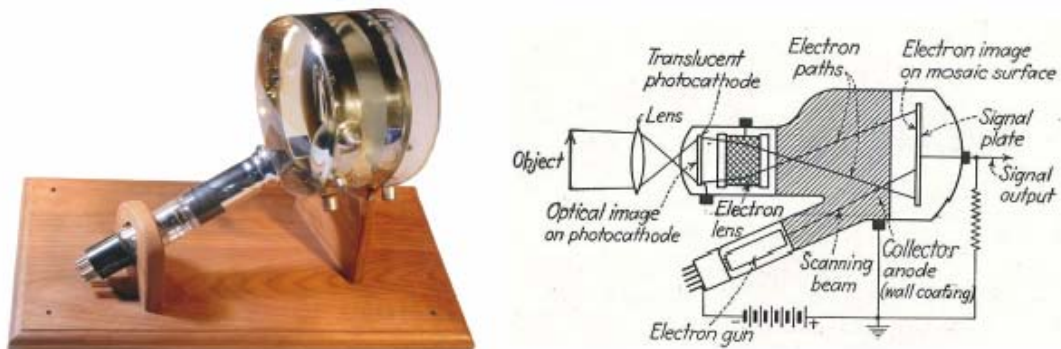


Figure 4

## The Image Orthicon

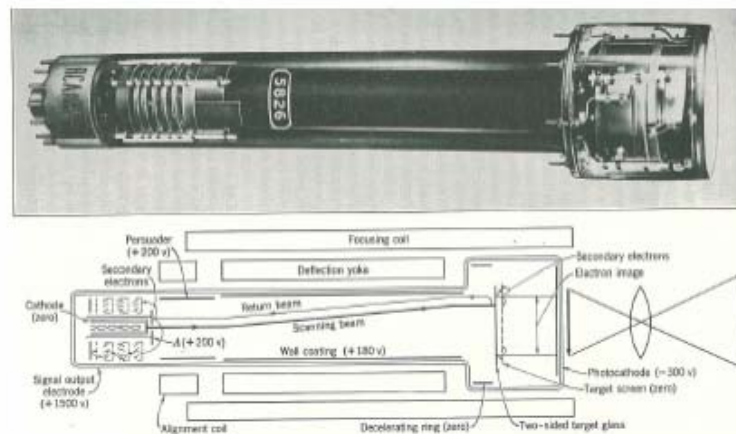


Figure 5

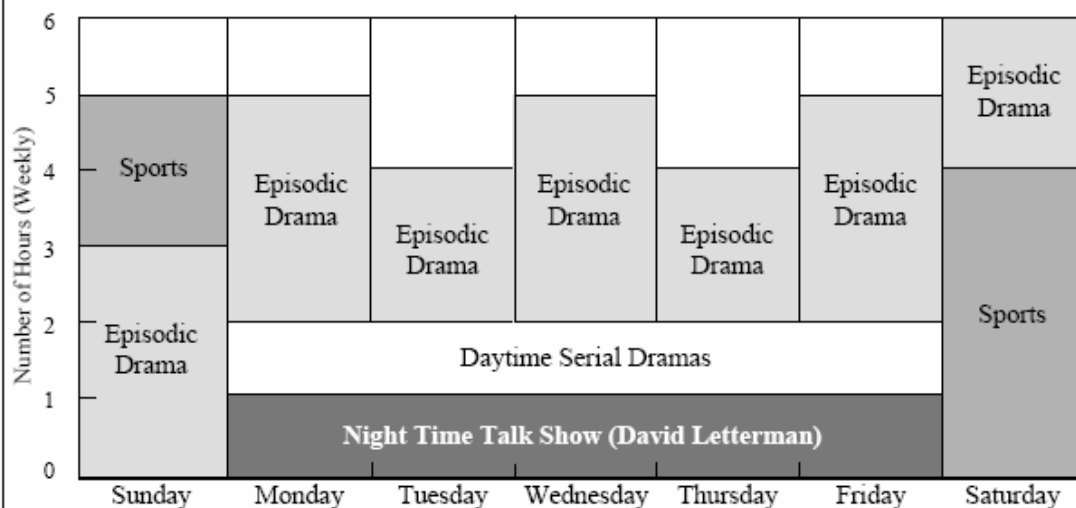




Joseph A. Flaherty   Francis F. Coppola   Joseph Polansky   Takashi Fujio

Figure 6

## CBS HD 1920/1080 Weekly Broadcast Schedule



**Total HD = 34 Hours per Week**

Figure 7



## CBS SPORTS PROGRAMMING PRODUCED IN 1920/1080I

---

	<u>Hours Per Year</u>
<b>U.S. Open Tennis . . . . .</b>	<b>18</b>
<b>Masters Golf Tournament . . . . .</b>	<b>12</b>
<b>NCAA Final Four Basketball Playoffs . . . . .</b>	<b>160</b>
<b>NCAA Football (weekly) . . . . .</b>	<b>70</b>
<b>NFL Post Season Football . . . . .</b>	<b>20</b>
<b>AFC Divisional Football Playoffs . . . . .</b>	<b>20</b>
<b>Super Bowl XXXVIII . . . . .</b>	<b>6</b>

NOTE:

AFC = American Football Conference.  
 NCAA = National Collegiate Athletic Association.  
 NFL = National Football League.

**Total = 306 Hrs**

Figure 8

## Cable Channels with Distribution of Programs Originating in HD

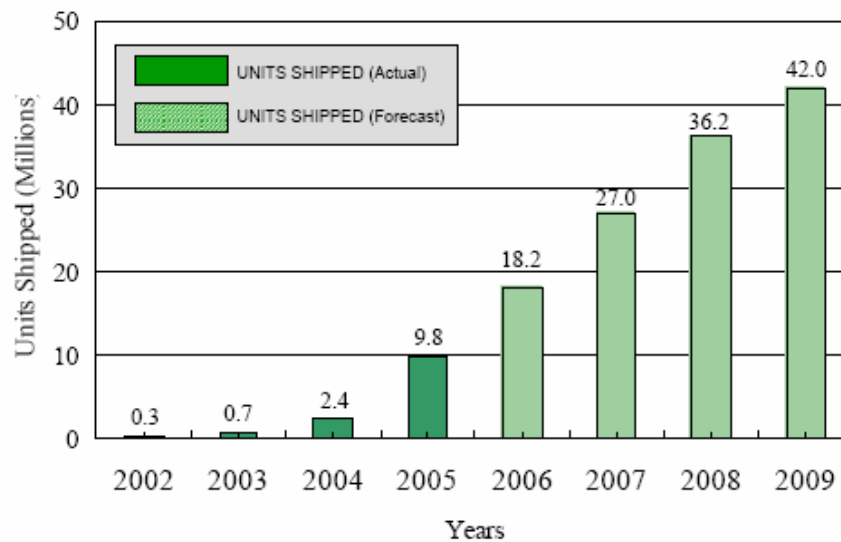
---

A&E HD	Madison Square Garden
Anamania HD	MTV HD
Bravo HD	MTV HD
Cinemax HD	NBA-HD
Comcast Sports Net	Playboy Spice Channel
Discovery HD	Sharper Movies-HD
Encore HD	Showtime HD
HBO-HD	Spike-HD
HD Classics	Starz HD
HD Epics	Starz HD Movies on Demand
HD News	The Movie Channel HD
HD Net	TMC-HD
HD Net Movies	TNT in HD
HD Studios	Turner Entertainment Network
HGTV-HD	Voom Cinema
History Channel	Voom-2
IMHD Movie Network	World Sports Net
IMHD-2 Movie Network	

These 37 channels distribute over 1900 hours of programming per week.

Figure 9

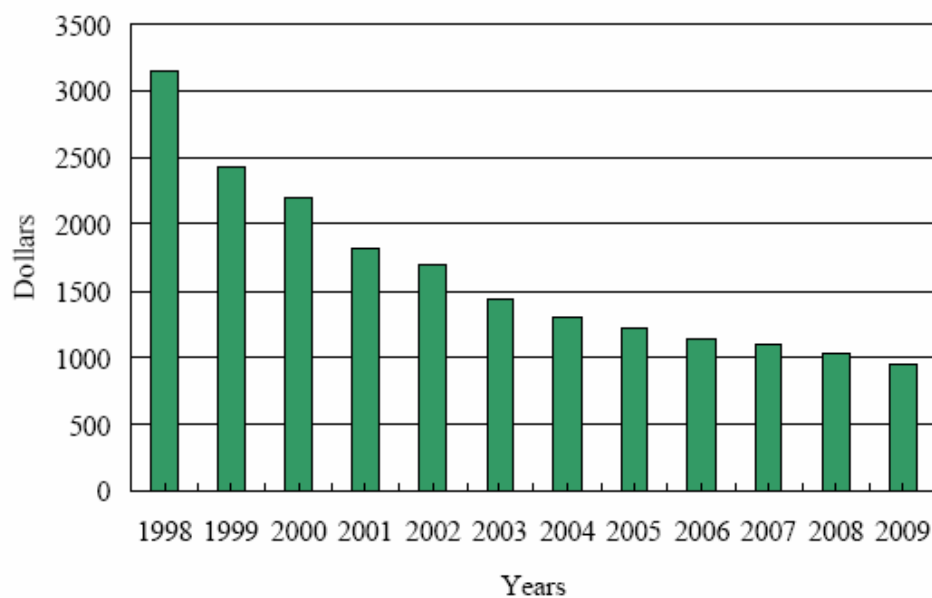
## Total HDTV Set Unit Sales



Source: CEA

Figure 10

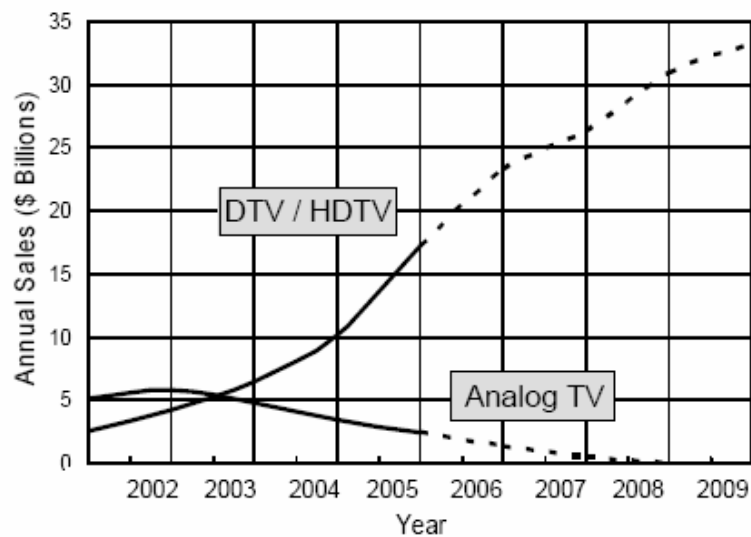
## Average Prices of Digital HDTV Sets



Source: CEA

Figure 11

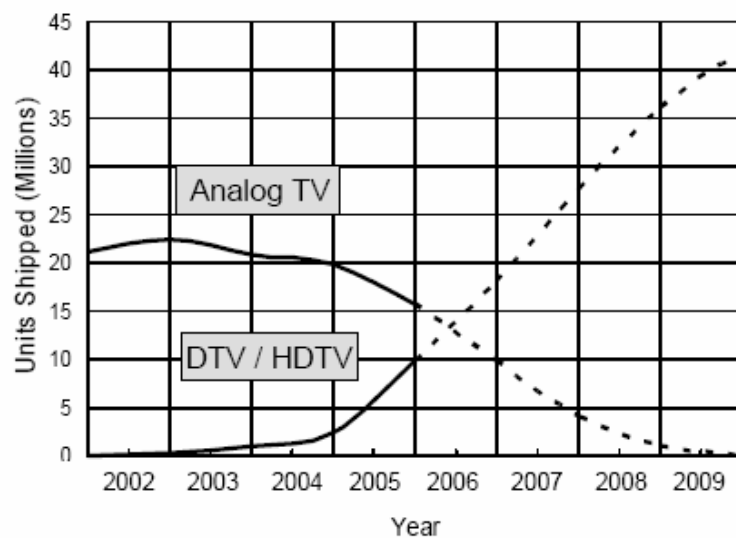
## DTV/HDTV & Analog TV Set Sales Revenues



Source: CEA

Figure 12

## DTV/HDTV Units & Analog TV Units Sold



Source: CEA

Figure 13

# General Session

# "Super Hi-Vision" future television

Masayuki Sugawara  
NHK Science and Technical Research Laboratories  
1-10-11 Kinuta Setagaya-ku Tokyo 157-8510 Japan  
sugawara.m-fq@nhk.or.jp

## Abstract

*"Super Hi-Vision" is the nickname of an ultrahigh-definition television system with 4000-scanning-line video and 22.2 multichannel sound. NHK is developing it with the aim of creating a broadcasting system that conveys a strong sensation of presence. This paper briefly describes its concept, history, R&D status, and human factors.*

## 1. Introduction

Increasing the number of scanning lines was one of the most important issues during the early stages of television development because viewers found that early TVs with fewer scanning lines were unsatisfactory. In fact, when a 200 scanning line system was developed in 1932, it was called "high definition". After 525 and 625 scanning line systems were developed, they became standards that have lasted for several decades [1].

The research on HDTV started at NHK's Science and Technical Research laboratory about 40 years ago [2]. Since then, broadcasting engineers all over the world have worked to make HDTV a reality. Each piece of technology and equipment along the broadcast signal chain had to be developed anew, and psycho-physical investigations of HDTV's effect on viewers and international standardization activities to make HDTV more effective and efficient had to be undertaken. As a result of these efforts, we are now witnessing the evolution from SDTV to HDTV.

We believe that it is not too early to start the research on the next generation of television now. As the history of HDTV suggests, we believe it would take a long time to develop and deploy a new television system. Although we started research on an ultrahigh-definition camera in 1995 [3], at that time, we were not thinking of it as part of the Super Hi-Vision television system. The original goal was simply to explore new media for HD and SD program production. We set our goals for developing a next-

generation television and started research on every part of its broadcasting chain in 2002 [4].

## 2. Image format of Super Hi-Vision

When we started our research, we faced a Chicken and Egg dilemma about the image format. That is, unless we created the equipment, we could not conduct the experiments that would give us data to determine a suitable image format. Yet without a decision on the image format, how could we make the equipment? Finally, we decided on a preliminary image format by taking past research into account. Table 1 lists the major specifications of the Super Hi-Vision signal format. The pixel count is 7680 x 4320, which provides a viewing angle of 100 arc-degrees horizontally when the viewer watches the screen at the standard viewing distance. Here, the standard viewing distance is defined as the shortest distance at which the scanning line structure is unrecognizable by a person with 20/20 vision.

Table 1: Signal format of Super Hi-Vision

Parameter	Value
Picture rate	60 frames/sec
Scanning	Progressive
Sample per active line	7680
Active lines per picture	4320
Picture aspect ratio	16:9

We realized that interoperability with the present HDTV system would be desirable, and the use of commercially available HDTV equipment would make system implementation easier. Hence we made the pixel count of Super Hi-Vision exactly four times larger (both horizontally and vertically) than that of HDTV, namely 1920 x 1080. Figure 1 compares the spatial and temporal resolutions of Super Hi-Vision with those of the media that are currently used or under study. Large screen digital imagery (LSDI) has

been under study at the International Telecommunication Union Radio-sector (ITU-R). Some of the research results on Super Hi-Vision were contributed to this organization's international standardization activities, and they are now reflected in an ITU-R Recommendation and Report [5, 6].

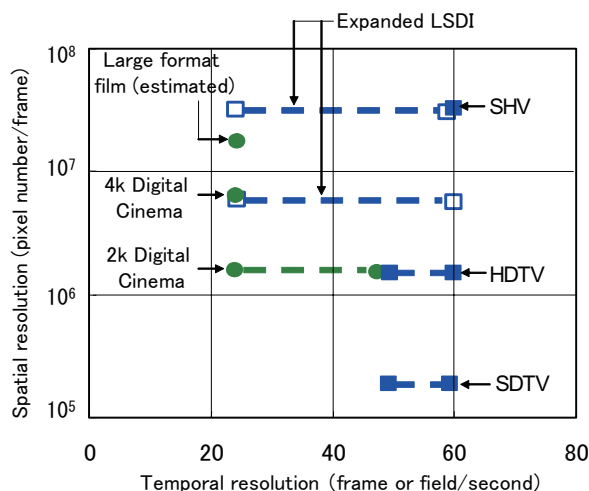


Figure 1: Resolutions of Super Hi-Vision and other systems

### 3. Current R&D status

Figure 2 shows the current state of our R&D efforts on the broadcasting program chain.

#### • Basic equipment

The first Super Hi-Vision camera system was based on four-CCD image-acquisition technology: two 2.5-in. 8M-pixel CCDs are used for green, and one each for red and blue [7]. The four-CCD beam-splitting system incorporates a two-dimensional pixel offset to form a Bayer color-sampling pattern with the CCDs. The second version of the Super Hi-Vision camera is equipped with four 1.25-in CMOS sensors [8]. The display system is similar to the imaging system; it uses four 8M-pixel LCDs to realize a 4000-scanning-line display, one LCD for red, one for blue, and two for green with diagonal pixel offset [9]. Recording equipment is based on parallel operation of high-definition hard disk drives. The component devices are connected using 16 optical fiber or coaxial cables based on the HD-SDI standard.

• Live transmission of uncompressed material through optical fiber Network [10]

On November 2, 2005, NHK conducted the first relay transmission of uncompressed Super Hi-Vision image and 22.2 multichannel sound signals. The experiment was conducted over a 260-km distance via an optical fiber network in real-time. We connected the Kamogawa Sea World aquarium (production site) and the NHK STRL (presentation site) by dark fibers belonging to several telecommunication companies. Such a large-capacity data transmission was made feasible through dense wavelength division multiplexing (DWDM). The picture and sound should be sent with a small delay so that newscasters and reporters can conduct a smooth conversation during live broadcasts. In this regard, the delay in transmission of Super Hi-Vision was only 4 ms, which is shorter than the frame period.

#### • Coding system [11]

A video codec based on the MPEG-2 coding scheme has been developed for efficient transmission and recording of Super Hi-Vision signals. The codec system consists of a video format converter, a video codec, and an audio codec. The video format converter converts the 7680 x 4320 (G1, G2, B, R) format from/into sixteen 1920 x 1080/30 PsF (Y/C 4:2:2) images, where the Super Hi-Vision image is divided spatio-temporally. The video codec consists of four sub-codecs for 3840 x 2160 images. A sub-codec contains four single-unit MPEG-2 HDTV codecs and a multi-channel frame synchronizer.

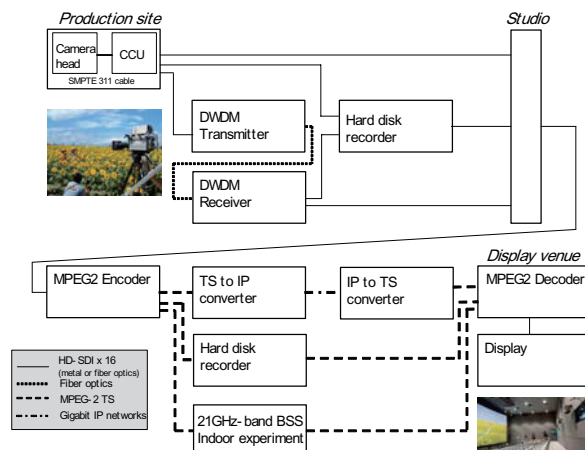


Figure 2: Super Hi-Vision system under development

- 21-GHz-band satellite transmission experiment [12]

The next-generation transmission systems for 21-GHz-band satellites have been investigated in the expectation that they can achieve higher bit-rate transmissions than present systems. An indoor transmission experiment was conducted using an experimental satellite transponder. A Super Hi-Vision signal compressed to a bitrate of 200 Mbps was divided into four channels. Each TS generated by the sub-encoder was modulated with a TC-8PSK, and then up-converted and amplified with a traveling wave tube (TWT) in the 21-GHz band. The TWT successfully transmitted signals for over 10 hours in total. The results suggested that Super Hi-Vision broadcasting via a 21-GHz band satellite is a possibility.

#### 4. Researches from the aspect of human factors

A thorough knowledge of human factors, especially the response of the human visual system to such a system, will be indispensable to the design of the system. We consider that our research scheme should embody the following aspects of human factors. Firstly, subjective evaluations are indispensable when we design the system. Secondly, objective (physiological) evaluations are useful as a complement to subjective ones because subjective evaluations may be time-consuming. Furthermore, physiological evaluations would provide us with a useful perspective for studying the human visual system in regard to the design of such a futuristic audio-visual system. Thirdly, negative effects such as motion sickness induced by video should be taken into account when designing the system.

Recent researches at NHK STRL have revealed following facts [13, 14, 15].

- To determine the relationship between viewing angle and sensation of presence, we conducted subjective evaluations and body-sway measurements. An experiment using a large display (over 300 inches) showed that the sensation of presence increases with the widening of the viewing angle. The perceived sensation improvement tapers off as the angle exceeds 70 to 100 arc-degrees.
- We also studied an issue related to motion sickness induced by video, which affects some people who

view large displays. We verified that symptom of motion sickness induced by vibrating images could be detected through electrocardiography (ECG).

Ultrahigh-definition images, which are most effective in large, wide-screen video presentations, will also present a new possibility for a relatively small display. To clarify this idea, let us consider the relationship between viewing distance and display size with the help of Figure 3. The figure depicts the relationship between viewing distance and display size, with the standard viewing distance condition being the straight line. For a given display size, the pixel structure cannot be distinguished at any viewing distance that falls on the right side of the straight line.

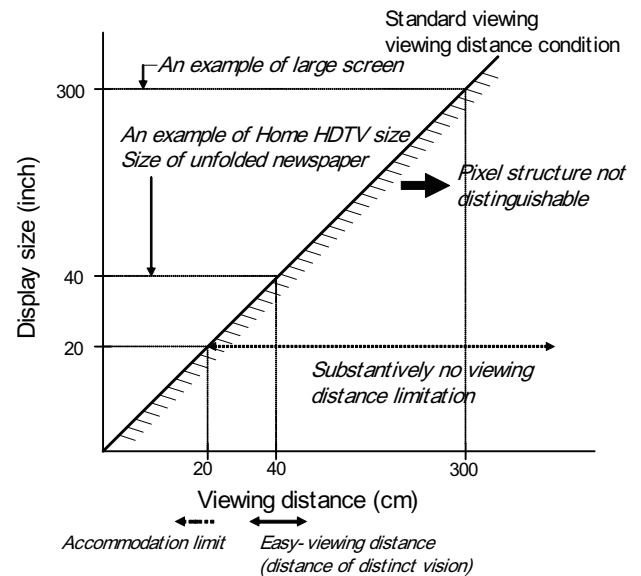


Figure 3: Viewing distance and display size for Super Hi-Vision

It is said that the natural distance for a human to observe an object distinctly, such as when reading a piece of printed material held in the hand, is around 40 cm, which is called the distance of distinct vision. For Super Hi-Vision, the display size at which this distance of distinct vision becomes the standard viewing distance is approximately 40-inches. This is equivalent to the size of a present home HDTV display, or an opened-up newspaper. Assuming that a display of such a size could be observed from a distance of 40 cm raises a number of potential applications. One possibility is that by watching the entire screen from a distance of about 2 m, the viewer would experience an effect similar to viewing HDTV,



but getting closer to the display, to about 40 cm (maintaining the same image) the viewer could view of a portion of the image with much more clarity. Such freedom in selecting the viewing distance without any concern for picture quality is not possible with conventional video systems, and it may have useful applications in medicine, education, or art appreciation.

A display size of 20-inches would have a standard viewing distance of 20 cm, which is close to the accommodation limit (near-point of accommodation) at which no pixel structure can be distinguished at any distance. Thus, Super Hi-Vision would effectively have a free viewing distance capability. This type of video presentation on a flexible display device would be the equivalent of a gravure printed magazine that is able to show motion pictures.

## 5. Conclusion

This paper described the Super Hi-Vision television system, which we are researching as part of our plan of developing a future broadcasting system. The goal of Super Hi-Vision is to provide a better visual experience, especially a stronger sensation of presence, to viewers. For that purpose, the display has a viewing angle of up to 100 degrees and its picture quality is excellent. Super Hi-Vision is still in the early stage of research and development. This paper described some of the work that is being conducted from diverse aspects, including the development of equipment, system integration, and human factors.

If we consider the system from the aspect of its worth as a "visual interface", we can conclude that Super Hi-Vision satisfies the fundamental human desire to watch what exists at distant places and that it is among the most visual of any media developed so far. It would expand the possibilities of visual interface technologies. Besides its suitability for large and wide screens, if Super Hi-Vision could be shown on rather small but high-pixel-density screens, it would be a video medium with virtually invisible pixels.

## References

- [1] A. Abramson, "The History of Television, 1880 to 1941", McFarland & Company, Inc., Publishers, Jefferson, North Carolina (1987).
- [2] NHK Science and Technical Research Laboratories, "HIGH DEFINITION TELEVISION Hi-Vision Technology", Van Nostrand Reinhold, New York (1993).
- [3] K. Mitani et al., "2k x 2k Image Acquisition System Using Four CMD Imagers", ITE Technical Report, vol. 19, no. 7, pp. 51-56 (1995).
- [4] M. Sugawara et al., "Progress on Large, Wide-screen Image Presentation - 4000-scanning-line TV aims at a medium that is provocative yet pleasing to the senses", Broadcast Technology, no. 18, pp. 5-9 (2004).
- [5] Recommendation ITU-R BT.1769 Parameter values for an expanded hierarchy of LSDI image formats for production and international programme exchange (2006).
- [6] Report ITU-R BT.2053 Large screen digital imagery (2005).
- [7] K. Mitani et al., "Ultrahigh-definition color camera system with 4K-scanning lines", Proceedings of SPIE, vol. 5017-18 (2003).
- [8] H. Shimamoto et al., "An 8k x 4k Ultrahigh-Definition Color Video Camera with 8M Pixel CMOS Imager", SMPTE Motion Imaging Journal 2005(July/August), pp.260-268 (2005).
- [9] M. Kanazawa et al., "A wide-screen projector of 4k x 8k pixels", IDW'02, pp. 1241-1244 (2002).
- [10] T. Nakatogawa et al., "Long-haul Transmission Experiment using Dense Wavelength Division Multiplexing with 16 Carriers for Uncompressed Super Hi-Vision Signal", ITE Technical Report, BCT2006-18 (2006).
- [11] Y. Nishida et al., "MPEG-2 Codec for Super Hi-Vision", IEICE General Conference, D-11-26 (2006).
- [12] H. Sujikai et al., "Indoor Transmission Experiment of Super Hi-Vision in the 21GHz Band", ITE Technical Report, BCT2006-23 (2006).
- [13] K. Masaoka et al., "Contrast Effect in Evaluating the Sensation of Presence for Wide Field-of-View", IEICE Technical Report, IE2006-15, pp. 19-24 (2006).
- [14] M. Emoto et al., "Viewing angle effects from wide field video projection images on the human equilibrium", Displays, vol. 26, no. 1, pp. 9-14 (2005).
- [15] M. Emoto et al., "Viewing angle effects from wide-field video system on visual-induced motion sickness", ITE Technical Report, vol. 30, no. 22, pp. 25-28 (2006).

# Visual Content Production and Digital Technology

Mitsuru Kaneko, Ph.D.

Tokyo University of Technology

1404-4 Katakura, Hachioji, Tokyo, Japan

[mits@media.teu.ac.jp](mailto:mits@media.teu.ac.jp)

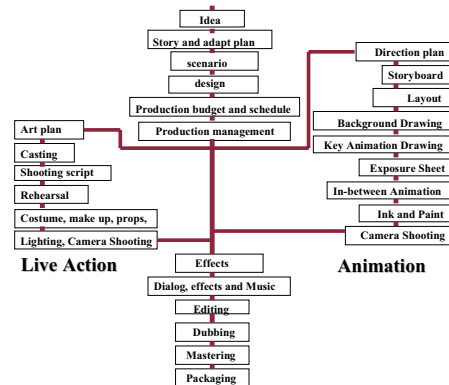
## Abstract

Cinema was invented almost over 100 years ago as the first generation of the visual contents. Now its form is transforming from Film to Digital. The influence of digital transition affects almost all the production process.

In this report, I speak about the major changes derived from Digital Technology, especially on the process which has not been changed from the early days. A Scenario Engine, can forward keywords of a screenplay to the production staff to create designs, storyboards, settings, and to the assistant directors for arrangements. A Design Engine can design characters and background models using the relating image database. A Diorama Engine will allow directors to simulate his direction plan without asking actor's participation. And finally, connecting all the engines, to make the best of digitalization, development of production control system called a Digital Production Assistance is about to complete

Processes of Production stage and Planning stage had been film and analog video oriented until recently. Although word processor and paint tools are applied to Screenplay writing and designing at Planning stage, the usage of digital technology was limited only within the individual process so that any data or information generated by a screenplay writer or designer have to be carried manually forward to the following process. Mail boys, assistants to producers and directors are running around production team to convey the latest changes and information.

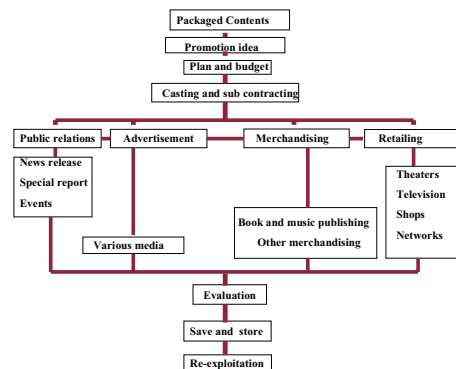
## Current Process of Visual Content Production



## 1. Introduction

According to the visual content production process analysis under research at Tokyo University of Technology (TUT), the whole production procedure of a typical cinema can be divided to almost 50 processes. These processes can be categorized to three major stages, which are Planning (Pre-Production) stage, Production stage and Post-Production (Activation) stage. While the most of Activation processes including editing, compositing, mixing, dubbing are digitally transformed since many years ago,

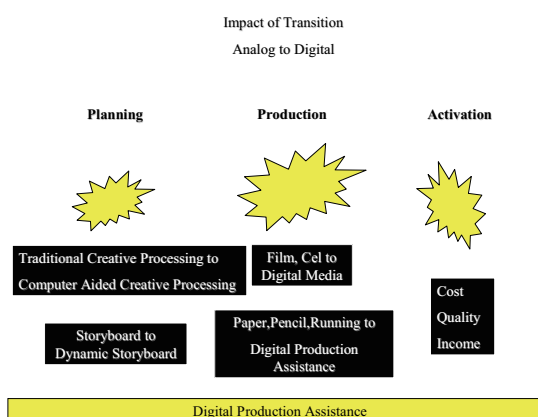
## Current Process of Visual Content Business



(Process list of Planning, Production and Activation stages of a visual content)

Among at Production Stage, digital technology has changed animation process almost totally. It is now all done by computer graphics, no celluloid or film are used during the production stage any more. Live action shooting was a little late on digitalization. Digital camera has been taking over film camera only recently. Many directors, cinematographers are still suspicious on digital camera on resolution, color and lighting expression. At Activation Stage, most processes are done digitally, but all of Cinema content is transformed to film when it is exhibited through theaters except for a few cases.

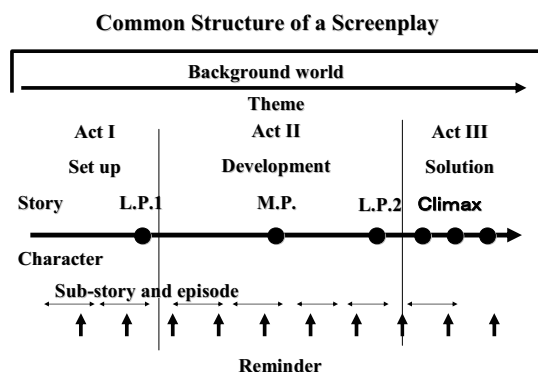
Now, digitalization moves quickly into all three stages as computers become faster, networks get cheaper, wider and better.



## 2. Digital Changes at Planning stage

Scenario writing especially in Japan has not used digital technology as in English speaking countries except for word processing. No screenwriting software such as Dramatica or Final Draft had been developed and used in Japan. A Scenario Engine in development at TUT is more than writing software but job instruction software to the following production process. Using XML, keywords and meanings are carried forward to designers, art staff and to directors

to make easy preparation for their jobs.



( Structure of a Screenplay)

**A Sample Interface of Scenario Engine**

タイトル	作成者	作成年月日時間	ドラマカーブ	分・秒数 (本シーン/累計残り)
参照プロット	S	M	L	F
エピソード	テーマ	背景世界	登場人物	相関図
	バックストーリー	サブストーリー	サブエピソード	

第一章 登場

1-1 1 いつもの生活 (表示プロット名)

↑ スクロール ↓

1-1 場所 時間 (注)

場所、時間、天候等の詳細説明 (ト書き)

登場人物・オブジェクトの配置と動き

登場人物名「 (せりふ) 」

登場人物名「 (せりふ) 」

登場人物・オブジェクトの移動と動き

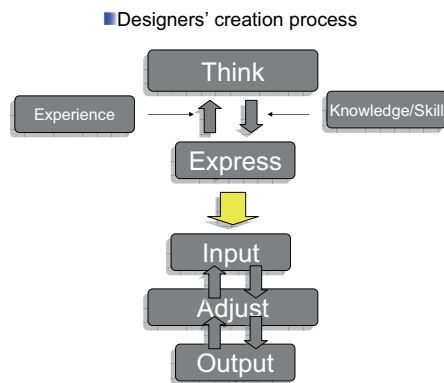
登場人物名「 (せりふ) 」

登場人物名「 (せりふ) 」

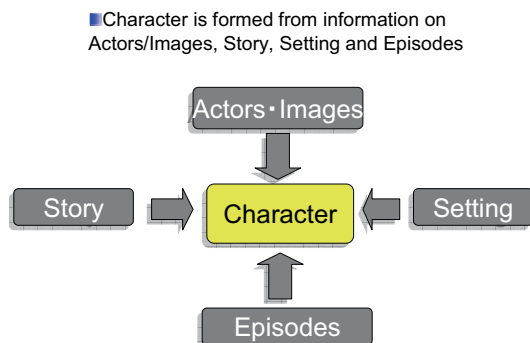
1-2 場所 時間 (注)

(Sample interface of a Japanese screenplay writing software)

Character designing is a matter of talent. If you cannot draw, you cannot be a designer. This had been true until Computer got enough power to help humans. Design Engine is a result of analyzing designers' work process on paper, pencil and brain. Designers can only create designs when he or she has seen or experienced something similar before. His or her brain remembers the images and instructs to hand to draw. Computer can help the user bringing samples by way of database and by way of drawing software. Not everyone who use the Design Engine can be as good as designers, but everyone can create example images to show his or her idea to the designers.



(Work Analysis of a character/background designer)

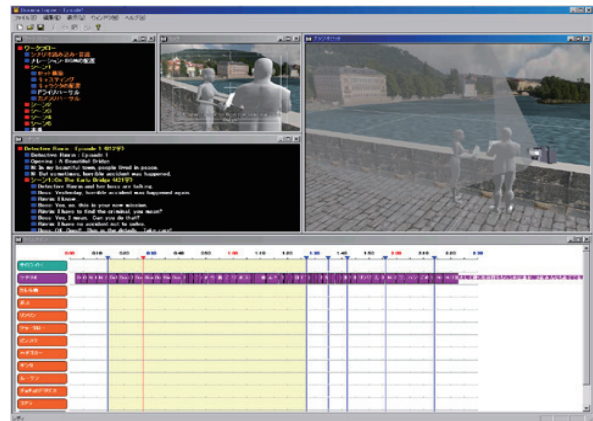


( Sample Interface of Design Engine)

Dynamic Storyboard has been in development for the purpose of directors simulation. In live action production, a director concretes his or her plan by rehearsal, which is costly and time limited. With the Diorama Engine a director can put background objects on the virtual floor, position the cast, put camera and lights and then move characters and camera as he or she plans. If it is not good, try the other way.

### 3. Digital Changes at Production stage

By using diorama engine, a director's job of direction becomes time effective. Camera and light positions are pre-determined and are informed to the cinematographer and his team as simulated images. Set preparation will be also time effective since art director knows well in advance about what the director wants.



(Sample Interface of Diorama Engine)

In computer graphics production, motion data are obtained by motion capturing live performers and are integrated to computer models. Another new method to simulate good old cartoon action data is in development at TUT.

#### Motion Capturing of Cartoon animation

( Sample motion data of an old cartoon)

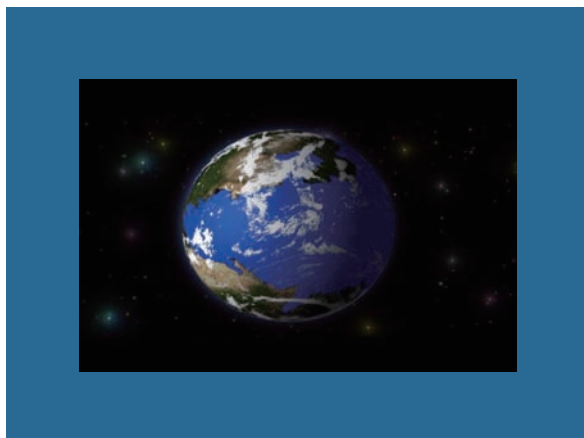
Copyright of the cartoon footages like this in some countries is still valid and in some countries not. What about the motions and actions of the characters which the animators created for these animated footages many years ago?

Good old movies' data on lighting can be databased as the sheet shows here. Number of lights, strength, location and direction of lights are 3D analyzed so that this sheet can be used both for live shooting and CG. The question of copyright arises here too.

参考資料 一分析表一									
シーン番号	シーン名	シーン内容	シーン画像	シーン音声	シーン効果音	シーン照明	シーンカメラ	シーン編集	シーン演出
001	オープニング	オープニングシーン	オープニング画像	オープニング音声	オープニング効果音	オープニング照明	オープニングカメラ	オープニング編集	オープニング演出
002	第1話	第1話シーン	第1話画像	第1話音声	第1話効果音	第1話照明	第1話カメラ	第1話編集	第1話演出
003	第2話	第2話シーン	第2話画像	第2話音声	第2話効果音	第2話照明	第2話カメラ	第2話編集	第2話演出
004	第3話	第3話シーン	第3話画像	第3話音声	第3話効果音	第3話照明	第3話カメラ	第3話編集	第3話演出
005	第4話	第4話シーン	第4話画像	第4話音声	第4話効果音	第4話照明	第4話カメラ	第4話編集	第4話演出
006	第5話	第5話シーン	第5話画像	第5話音声	第5話効果音	第5話照明	第5話カメラ	第5話編集	第5話演出
007	第6話	第6話シーン	第6話画像	第6話音声	第6話効果音	第6話照明	第6話カメラ	第6話編集	第6話演出
008	第7話	第7話シーン	第7話画像	第7話音声	第7話効果音	第7話照明	第7話カメラ	第7話編集	第7話演出
009	第8話	第8話シーン	第8話画像	第8話音声	第8話効果音	第8話照明	第8話カメラ	第8話編集	第8話演出
010	第9話	第9話シーン	第9話画像	第9話音声	第9話効果音	第9話照明	第9話カメラ	第9話編集	第9話演出

( Sample data sheet of lighting of old movies)

4K resolution animation Test Production seems to be too much for Anime. But it is good to provide information of how to deploy characters and models in a frame, how the action can be exaggerated or limited, what kind and number of colors should be selected for high quality images.



(Test Production of 4K Anime production)

#### 4 Digital Changes at Activation stage

Digital post-production processes such as contrast and color correction, sound relocation and mixing, composition, editing, dubbing, and mastering has been industrial standard for several years. Soon the current film conversion will be eliminated as the theaters have equipped with the 2K and 4K digital projectors. The cost of film printing, transporting and maintaining will be gone because of replacing film to digital high speed data transmission.

Visual output by a digital projector is always clean, clear (depends upon the resolution) and bright. If it is not bright enough because of distant screen or ambient light, two projectors can project exactly the same frame images for pinpoint projection.

Audio output by multiple speakers creates more realistic sound because a screen with many speakers printed will be available shortly. Sound mixing process for this type of screen exhibition, though, has to be more complicated.

#### 5 Digital changes at Production Control

A concept of Digital Production Assistance (DPA) has just started at research and test level. Elimination of film accelerates the movement of applying the concept to the whole entertainment production industry.

All process of visual content production from Planning stage to Activation stage can be audited daily just as the other production industry so that true creativity stands on the establishment of healthy academic ground of production.

#### 6 Future of Visual content production

To fulfill the increasing demand for new visual contents for Ubiquitous, home, classroom, auditorium and theater media, the production has to prepare for more resolution, more color expression, more detailed sound source expression using digital equipments.

Regardless of Interactive and non-interactive, the quality of visual content has to match with the demand for all media exhibition. Digital screenplay writing, digital designing, computer graphics simulation, 4K camera visual input, multi-microphone input, separated audio-visual track recording and mastering, network support for production and distribution will be the key technologies for the future digital content industry.

( Mitsuru Kaneko, 2006/09/11)

# Free Viewpoint Television

*Masayuki Tanimoto*

Graduate School of Engineering, Nagoya University  
Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan  
tanimoto@nuee.nagoya-u.ac.jp

## ABSTRACT

FTV (Free viewpoint TV) enables us to view a distant 3D world freely by changing our viewpoints as if we were there. FTV will bring an epoch-making change in the history of television since it is an ultimate 3D-TV and positioned as the top of image media because of its largest space of representation. We proposed the concept of FTV and verified its feasibility by the world's first real-time system including the complete chain from capturing to display. The international standardization on the compression of FTV is in progress. FTV is not a pixel-based system but a ray-based system. We are creating ray-based image engineering through the development of FTV.

## 1. INTRODUCTION

Television has a long and successful history since it realized a human dream of seeing a distant world in real-time. It stands as the most important visual information system. However, TV shows us the same scene even if we move our viewpoints in front of the display. It is quite different from what we experience in the real world. In TV, users can get only a single view of a real 3D world they want to see. The view is determined not by users but by a camera placed in the 3D world. Although many important technologies have been developed, this function of TV has never changed.

TV has been developed by pixel-based technologies. However, the most essential element of visual systems is not a pixel but a ray. We have been developing ray-based 3D information systems that consist of ray acquisition, ray processing, and ray display. FTV (Free Viewpoint Television) [1] - [3] is a typical example of such a system.

FTV will bring an epoch-making change in the history of television because it has a new function to view the 3D world freely as if we were there. The ray-space method [4] - [7] enables it.

We proposed the concept of FTV and verified its feasibility by the world's first real-time experiment [8], where a real moving object was viewed using a virtual bird's eye camera whose position was moved freely in a 3D space controlled by a 3D mouse.

FTV brings a new frontier to the field of signal processing since the signal processing of FTV such as coding and view image generation is performed in the ray-space that is a new domain with higher dimension than that of the current TV. A new user interface is also needed for FTV to make full use of 3D information of FTV.

As an ultimate 3D TV, FTV needs higher performance for all related devices, equipments and systems, and accelerates the development of electronic industry. As the next-generation TV,

it opens new applications in the fields of communication, entertainment, advertising, education, medicine, art, archives and so on. As information infrastructure for secure society, it increases security of public facilities, roads, vehicles, schools, factories and so on.

We proposed FTV to MPEG [2] and have been making contributions. It is considered the most challenging scenario in 3DAV (3D Audio Visual) of MPEG and the standardization of MVC (Multi-view Video Coding) has started [9], [10].

The FTV Committee was organized to promote MPEG standardization and to develop FTV applications in JEITA (Japan Electronics and Information Technology Industries Association) under the support of METI (Ministry of Economy, Trade and Industry). About 20 organizations including industries, carriers, broadcasters, content providers and so on participate this activity.

FTV can be a platform for various important 3D systems and the FTV signal can be a common signal format for the 3D systems.

It should be noted that FTV is not a conventional pixel-based system but a ray-based system. We have been developing the technologies of ray capturing, ray processing, and ray display [11].

## 2. RAY-SPACE REPRESENTATION

### 2.1. Ray-space method

We developed FTV based on the ray-space representation [4] - [7]. In the ray-space representation, one ray in the 3D real space is represented by one point in the ray space. The ray-space is a virtual space. However, it is directly connected to the real space. The ray-space is generated easily by collecting multi-view images with the consideration of camera parameters. Let  $(X, Y, Z)$  be three space coordinates and  $\theta, \phi$  be the parameters of direction. A ray going through the space can be uniquely parameterized by its location  $(X, Y, Z)$  and the direction  $(\theta, \phi)$ ; in other words, a ray can be mapped to a point in this 5-D ray parameter space. In this ray parameter space, we introduce a function  $f$  whose value corresponds to an intensity of the specified ray. Thus, all the intensity data of rays can be expressed by

$$f(x, y, z; \theta, \phi). \quad (1)$$
$$-\pi \leq \theta < \pi, -\pi/2 \leq \phi < \pi/2.$$

We call this ray parameter space the ray-space.

Although the 5-D ray-space mentioned above includes all the information viewed from any viewpoint, it is very redundant due

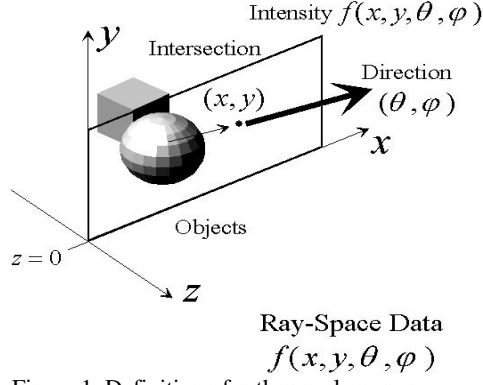


Figure 1. Definition of orthogonal ray-space.

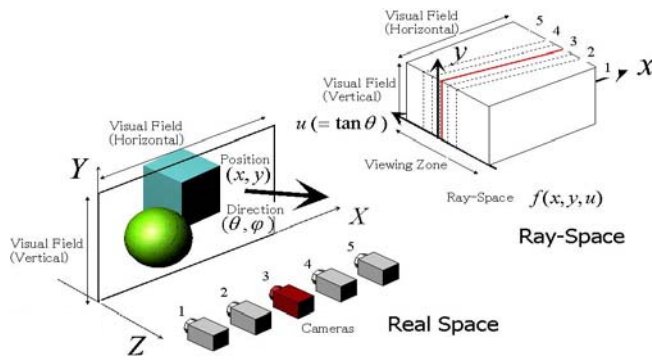


Figure 2. Acquisition of orthogonal ray-space.

to the straight traveling of rays. Thus, when we treat rays that arrive at a reference plane, we can reduce the dimension of parameter space to 4-D.

We use two types of ray-space for FTV. One is the orthogonal ray-space, where a ray is expressed by the intersection of the ray and the reference plane and its direction. Another is the spherical ray-space, where the reference plane is set to be normal to the ray [7]. The orthogonal ray-space is used for FTV with linear camera arrangement whereas the spherical ray-space for FTV with circular camera arrangement.

The definition of the orthogonal ray-space is shown in Fig. 1. The ray-space is 4-dimensional and 5-dimensional including time. If we place cameras within a limited region, the obtained rays are limited and the ray-space constructed from these rays is a subspace of the ray-space. For example, if we place cameras on a line or a circle, we have only one part of data of the ray-space. In such cases, we define smaller ray-space.

For the linear camera arrangement, the ray space is constructed by placing many camera images upright in parallel as shown in Fig. 2, forming the FTV signal in this case. The FTV signal consists of many camera images and the horizontal cross-section has line structure as shown in Fig. 3. The line structure of the ray-space is used for the ray-space interpolation and compression.

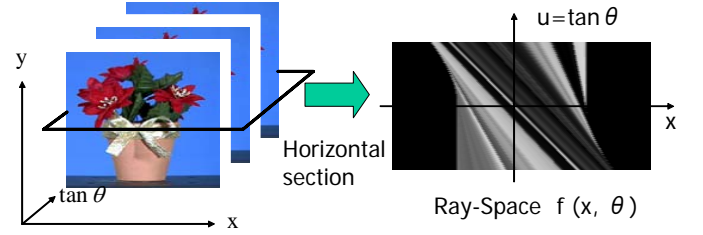


Figure 3. An example of orthogonal ray-space.

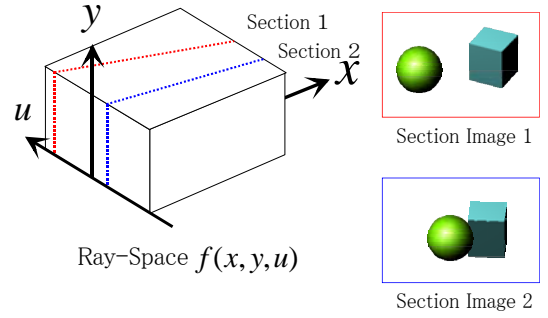


Figure 4. Generation of view images

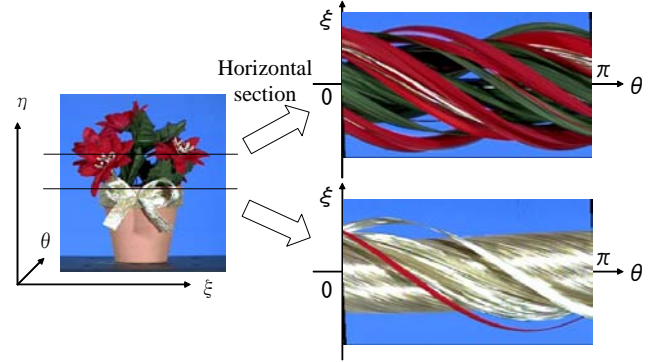


Figure 5. An example of spherical ray-space.

Vertical cross-sections of the ray space give view images at the corresponding viewpoints as shown in Fig. 4.

For the circular camera arrangement, the spherical ray space is constructed from many camera images and its horizontal cross-section has a sinusoidal structure as shown in Fig. 5. The sinusoidal structure of the ray-space is also used for the ray-space interpolation and compression.

The hierarchical ray-space [6] is defined for scalability.



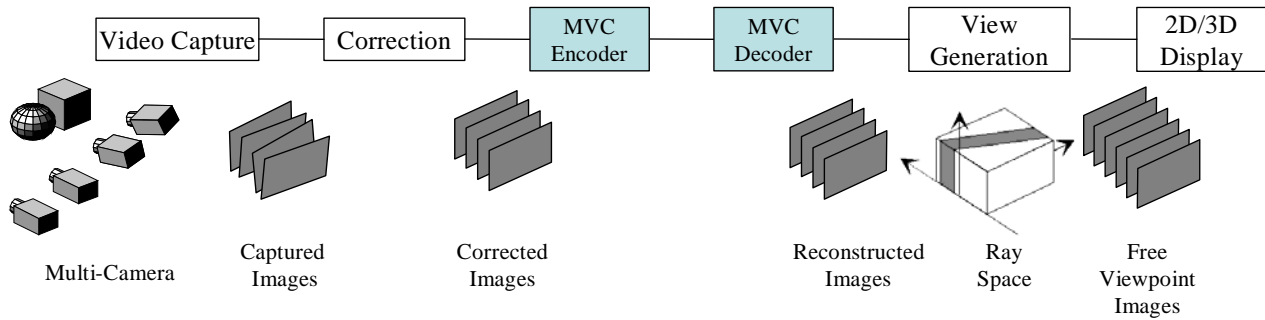


Figure 6. Configuration of FTV system.

### 3. FTV SYSTEM

#### 3.1. Configuration of FTV System

Fig. 6 shows the configuration of FTV system.

At the sender side, 3D scene is captured by multi-cameras. The captured images contain the misalignment and luminance difference of cameras. They should be corrected to construct ray-space. The corrected images are compressed for transmission and storage by the MVC (Multi-view Video Coding) encoder.

At the receiver side, reconstructed images are obtained by the MVC decoder. Ray-space is constructed by arranging the reconstructed images and interpolating them. Free viewpoint images are generated by cutting the ray-space vertically and displayed on a 2D/3D display.

The function of FTV was successfully demonstrated by generating photo-realistic free viewpoint images of the moving scene in real-time.

Each parts of Figure 6 are explained in more detail below.

#### 3.2. Capturing

We constructed a 1D arc capturing system shown in Fig.7 for a real-time FTV system covering the complete chain from video capturing to display [12]. It consists of 16 cameras, 16 clients and one server. Each client has one camera and all clients are connected to the server with Gigabit Ethernet.

A “100-camera system” has been developed to capture larger space by Nagoya University (Intelligent Media Integration COE and Tanimoto Laboratory) [13]. The system consists of one host server PC and 100 client PCs (called ‘nodes’) that are equipped with JAI PULNiX TM-1400CL cameras. The interface between camera and PC is Camera-Link. The host PC generates a synchronization signal and distributes it to all the nodes. This system is capable of capturing not only high-resolution video with 30 fps but also analog signal up to 96 kHz.

The camera setting is flexible as show in Fig. 8. MPEG test sequences “Rena” and “Akko&Kayo” as shown in Fig. 9 were taken by the camera arrangements of (a) and (c), respectively .



Figure 7. 1D arc capturing system.

#### 3.3. Correction

The rectification [14] and luminance compensation [15] of camera images are performed by measuring the correspondence points of camera images. This measurement is made once after the cameras are set.

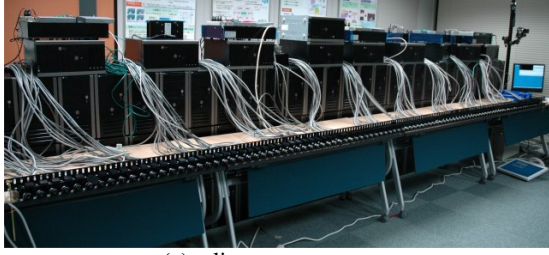
#### 3.4. MVC Encoding and Decoding

Standardization of compression of multi-camera images is progressing as MVC (Multi-view Video Coding) in MPEG. The detail is described in chapter 5.

#### 3.5. View Generation

Ray-space is formed by placing the reconstructed images vertically and interpolating them. Free viewpoint images are generated by making the cross-section of the ray-space.

Examples of the generated free viewpoint images are shown in Fig. 10. Complicated natural scenes including sophisticated objects such as small moving fishes, bubbles and reflection of light from the aquarium glass are reproduced very well.



(a) linear arrangement



(b) circular arrangement



(c) 2D array arrangement

Figure 8. 100-camera system.



(a) “Rena”



(b) “Akko&Kayo”

Figure 9. MPEG test sequences.

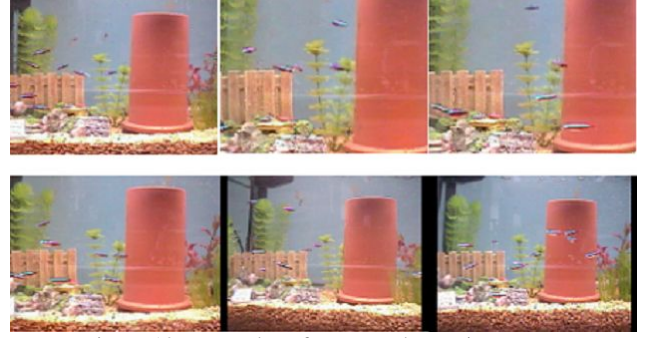


Figure 10. Examples of generated FTV images at various time and viewpoints.

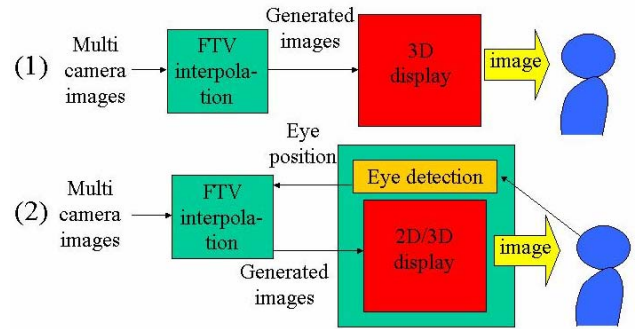


Figure 11. Display of FTV.

The quality of generated view images strongly depends on the interpolation. The ray-space interpolation is done by detecting depth information pixel by pixel from the multi-view video. We proposed several interpolation schemes of the ray-space [16]-[18].

The free viewpoint images are generation by a PC cluster in [12]. Now, they can be generated by a single PC and FTV on PC is realized in real-time [19].

### 3.6. 2D/3D Display

FTV needs a new user interface to display free viewpoint images. Two types of user interface were made using 2D and automultiscopic 3D displays with a head tracking system as shown in Fig. 11.

Many head tracking systems have been proposed using magnetic sensor, various optical marker, infrared camera, retroreflective light from retina, etc. Our head tracking system uses only a conventional 2D camera and detects the position of a user's head by image processing. The user doesn't need to attach any markers or sensors.

In the user interface using a 2D display, the location of the user's head is detected with the head tracking system and the corresponding view image is generated. Then, it is displayed on the 2D display as shown in Fig. 12.

Automultiscopic displays enable a user to see stereoscopic images without special glasses. However, it has two problems:



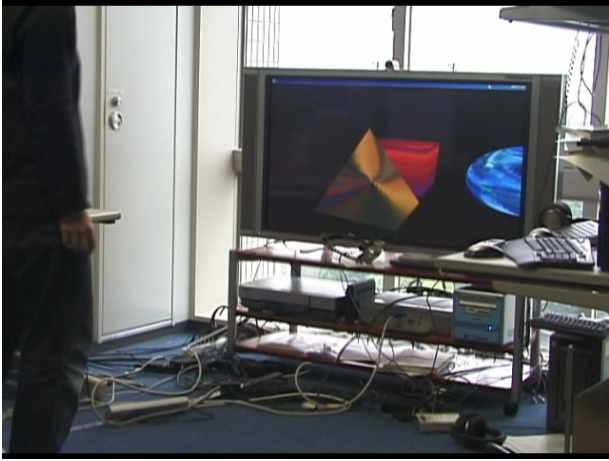


Figure 12. 2D display with eye tracking.



(a) without head tracking (b) with head tracking

Figure 13. 3D display with and without head tracking.

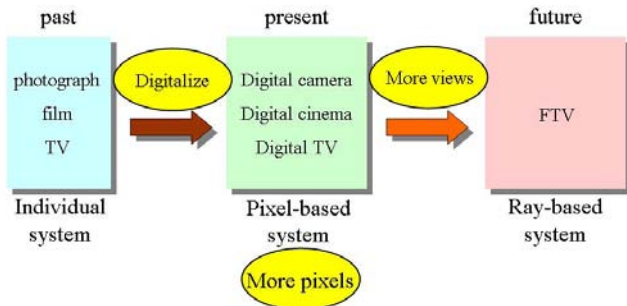


Figure 14. Evolution of image system.

limited viewing zone and discreteness of motion parallax. Because the width of viewing zone for each view equals the interpupillary distance approximately, the view image does not change by the viewer's movement within the zone. On the other hand, when the viewer moves over the zone, the view image changes suddenly.

In the user interface using the automultiscopic display, the function of providing motion parallax is extended by using the head tracking system. The feeded images change according to the movement of the head position to provide small motion parallax, and the view channel to feed image is switched for handling large motion. It means that binocular parallax for

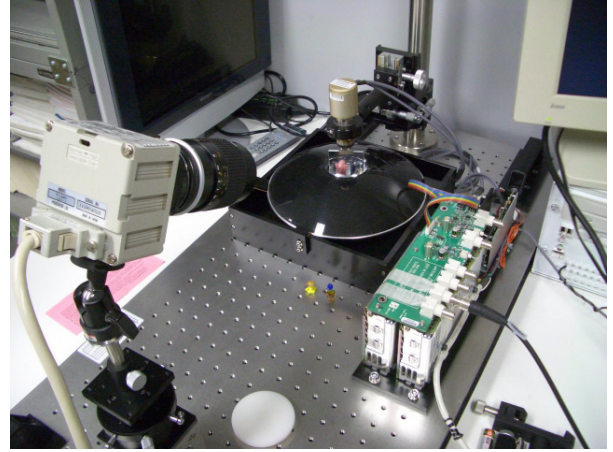


Figure 15. Mirror-scan ray capturing system.

eyes is provided by automultiscopic display and motion parallax is provided by head tracking and changing image adaptively as shown in Fig. 13.

## 4. EVOLUTION OF IMAGE SYSTEM

### 4.1. Progress of 3D Capturing and Display

Fig. 14 shows the evolution of image system. In the past, image systems such as photograph, film and TV were individual systems. At present, they are digitized and can be treated on the same platform as pixel-based systems. These pixel-based systems are developing toward more pixels. It is symbolized by Super High-Definition TV [20]. Although Super HDTV has about 100 times pixels of SDTV, view is still only one. In the future, needs for more pixels will be saturated and more views will be needed. This is an evolution from a pixel-based system to a ray-based system. We have been developing FTV according to this scenario. Roughly speaking, we can realize SD-FTV by using technologies of HDTV or Super HDTV and balancing pixels and views.

### 4.2. Ray Reproducing FTV

We are developing the ray reproducing FTV to create ray-based image engineering. The ray reproducing FTV consists of ray capturing, ray processing, and ray display.

We developed a new ray capturing system [21] as shown in Fig. 15. It acquires a dense ray-space without interpolation in real time. In this capturing system, a high-speed camera and a scanning optics system are used instead of multiple cameras. The important feature of this configuration is that the spatial density of a multi-camera setup is converted to a density in time axis, i.e. frame rate of the camera. This means that we can increase the density



Figure 16. 360 degree ray reproducing SeeLINDER display.

of the camera interval equivalently by increasing the frame rate of the camera. The scanning optics system is composed of a double-hyperbolic mirror shell and a galvanometric mirror. The mirror shell produces a real image of an object that is placed at the bottom of the shell. The galvanometric mirror in the real image reflects the image to the camera-axis direction. The reflected image observed from the camera varies according to the angle of the galvanometric mirror. This means that the camera can capture the object from various viewing directions that are determined by the angle of the galvanometric mirror. To capture the time-varying reflected images, we use a high-speed camera with an electronic shutter that is synchronized with the angle of the galvanometric mirror. We capture more than 100 view images within the reciprocation time of the galvanometric mirror. The collection of the view images is then mapped to the ray-space.

A 360 degree ray producing display SeeLINDER [22] that allows for multiple viewers to see 3D FTV images is shown in Fig. 16. It consists of a cylindrical parallax barrier and one-dimensional light source arrays. Semiconductor light sources such as LEDs are aligned in a vertical line for the one-dimensional light source arrays. The cylindrical parallax barrier rotates fast, and the light source arrays rotate to the opposite direction slowly. If the aperture width of the parallax barrier is sufficiently small, the light going through the aperture becomes a thin flux, and its direction is scanned by movement of the parallax barrier and the light source arrays. By synchronously changing the intensity of the light sources with the scanning, pixels whose luminosity differs for each viewing direction can be displayed.

Fig. 17 shows the progress of 3D capturing and display. In this figure, the ability of 3D capturing and display is expressed by a factor of pixel-view product that is defined as (number of pixels)×(number of views). In Figure 11, ① denotes the factor of the 100-camera system mentioned earlier. We have also been developing new types of ray capturing and display systems. Their factors are indicated by ② and ③ in Figure 14. ② is a mirror-scan ray capturing system[21] and ③ is a 360 degree ray reproducing SeeLINDER display [22]. They are explained in the next section.

In Fig. 17, the progress of space-multiplexing display follows Moore's Law because it is achieved by miniaturization. The factor of the time-multiplexing display is larger than that of the space-multiplexing display. The difference is given by time-multiplexing technology. The progress of capturing does not follow Moore's Law because it depends on the resolution of a camera and the number of cameras used.

The pixel-view product increases very rapidly year after year in both capturing and display. This strongly supports our scenario. We can see the three-dimensional image naturally and the images have strong depth cues of natural binocular disparity. When we move around the display, we see the corresponding images in our viewing position. Therefore, we perceive the objects just as if they were floating in the cylinder.

## 5. INTERNATIONAL STANDARDIZATION

MPEG established AHG on 3DAV (3D Audio Visual) and started 3DAV activities in December 2001 as shown in Fig. 18. First, many topics on 3D were discussed. Especially, the following 4 topics were studied intensively as EE's (Exploration Experiments).

- EE1 : omni directional video
- EE2 : free viewpoint
  - FTV (Ray-Space)
  - FVV (model based)
- EE3 : stereoscopic video
- EE4 : 3D-TV with depth disparity information

The discussion was focused on FTV and MVC (Multi-view Video Coding) in January 2004 because FTV got a strong support from industries in response to "Call for Comments on 3DAV". Then, the standardization of MVC started in January 2006.

MVC activity moved to Joint Video Team (JVT) of MPEG and ITU for further standardization process in July 2006.

The FTV system is not realized by multi-view video coding only. We have proposed to define FTV reference model that consists of several modules and to standardize the interface between modules under the support of SCOPE-I of MIC (Ministry of Internal Affairs and Communications) [23].

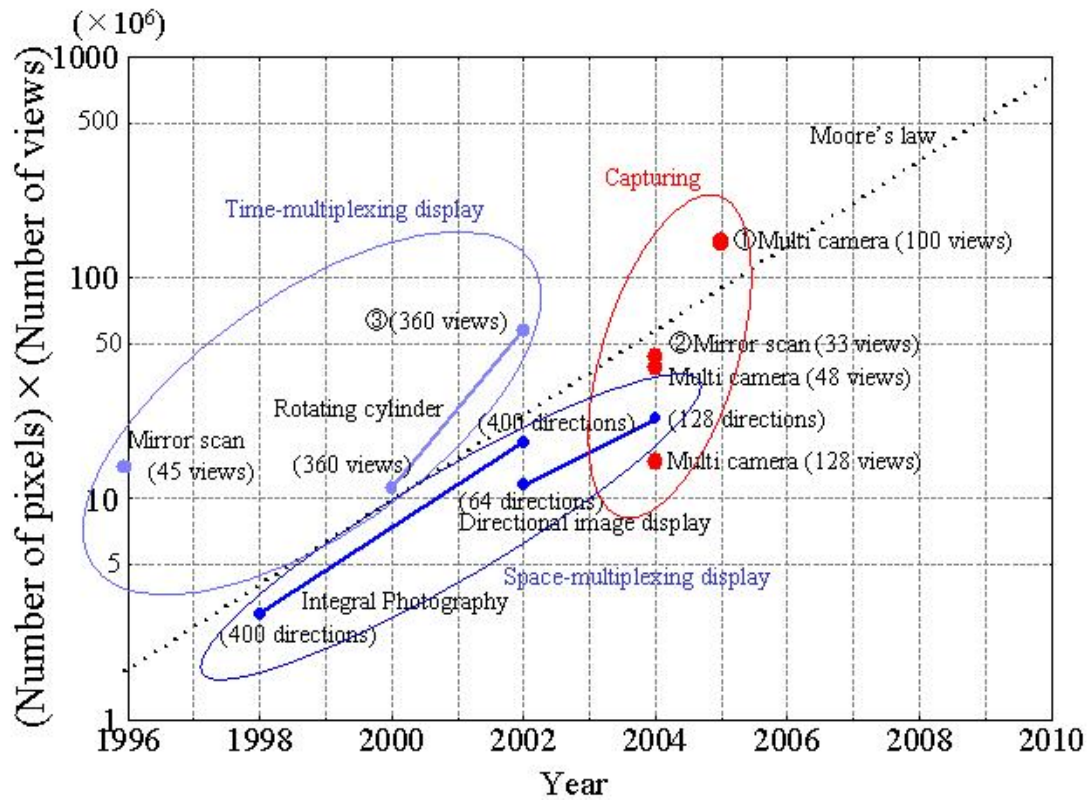


Figure 17. Progress of pixel-view product at 3D capturing and display.

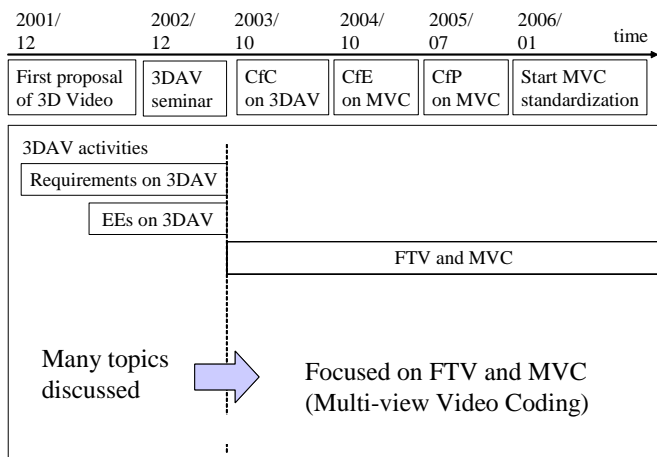


Figure 18. MPEG 3DAV activities and standardization of FTV coding

## 6. CONCLUSION

Ray is the most essential element of visual systems. We have been developing ray-based 3D information systems that consist of ray capturing, ray processing, and ray display. FTV is a typical example of such systems.

The processing of FTV can be performed in real-time on a single PC. Thus, we can enjoy FTV on PC if the new standard of MVC is available and compressed FTV contents are delivered with package media.

Furthermore, the technologies of ray capturing and display are making rapid progress. It accelerates the introduction of FTV into market as an ultimate 3D TV, a new tool for art and content creation, an information infrastructure for secure society, etc.

FTV is opening the way to ray-based image engineering that gives us frontier technologies to treat rays one by one.

## REFERENCES

- [1] Masayuki Tanimoto, "Overview of Free Viewpoint Television," *Signal Processing : Image Communication*, vol.21, no.6, pp.454-461, July 2006.
- [2] Masayuki Tanimoto, "Free Viewpoint Television - FTV", *Picture Coding Symposium 2004*, Session 5, December 2004.
- [3] M. Tanimoto and T. Fujii, "FTV — Free Viewpoint Television", *ISO/IEC JTC1/SC29/WG11*, M8595, July 2002.
- [4] T. Fujii, "A Basic Study on the Integrated 3-D Visual Communication", *Ph.D thesis of engineering*, The University of Tokyo, 1994(in Japanese).
- [5] T. Fujii, T. Kimoto and M. Tanimoto, "Ray Space Coding for 3D Visual Communication", *Picture Coding Symposium '96*, pp. 447-451, Mar. 1996.
- [6] M. Tanimoto, A. Nakanishi, T. Fujii and T. Kimoto, "The Hierarchical Ray-Space for Scalable 3-D Image Coding", *Picture Coding Symposium 2001*, pp.81-84, April 2001.
- [7] T. Fujii and M. Tanimoto, "Free-viewpoint Television based on the Ray-Space representation, " *Proc. SPIE ITCOM 2002*, pp.175-189, August 2002.
- [8] M. Sekitoh, T. Fujii, T. Kimoto, and M. Tanimoto, "Bird's Eye View System for ITS", *IEEE, Intelligent Vehicle Symposium*, pp. 119-123, 2001.
- [9] "Introduction to Multi-view Video Coding", *ISO/IEC JTC 1/SC 29/WG11*, N7328, July 2005.
- [10] "Call for Proposals on Multi-view Video Coding", *ISO/IEC JTC1/SC29/WG11*, N7327, July 2005.
- [11] Masayuki Tanimoto, "FTV (Free Viewpoint Television) Creating Ray-Based Image Engineering", *Proc. of ICIP2005*, pp.II-25—II-28, 2005.
- [12] Na Bangchang, T. Fujii and M. Tanimoto, "Experimental System of Free viewpoint TeleVision", *Proc. IST/ SPIE Symposium on Electronic Imaging*, Vol. 5006-66, pp. 554-563, Jan. 2003.
- [13] Toshiaki Fujii, Kensaku Mori, Kazuya Takeda, Kenji Mase, Masayuki Tanimoto and Yasuhito Suenaga, "Multipoint Measuring System for Video and Sound -100-camera and microphone system -", *IEEE 2006 International Conference on Multimedia & Expo (ICME)*, pp. 437-440 July 2006.
- [14] K. Matsumoto, T. Yendo, T. Fujii and M. Tanimoto, "Multiple-Image Rectification for FTV", *Proc. of 3D Image Conference 2006*, P-19, pp.171-174 (2006).
- [15] Kenji Yamamoto, Tomohiro Yendo, Toshiaki Fujii, Masayuki Tanimoto and David Suter, "Color Correction for Multi-camera System by using Correspondences," *ACM SIGGRAPH2006, Posters*, 30 July - 3 August 2006.
- [16] A. Nakanishi, T. Fujii, T. Kimoto and M. Tanimoto, "Ray-Space Data Interpolation by Adaptive Filtering using Locus of Corresponding Points on Epipolar Plane Image", *The Journal of the Institute of Image Information and Television Engineers (ITE)*, Vol. 56, No. 8, pp. 1321-1327, 2002.
- [17] M. Droese, T. Fujii and M. Tanimoto, "Ray-Space Interpolation based on Filtering in Disparity Domain", *Proc. 3D Conference 2004*, pp. 213-216, Tokyo, Japan, June 2004.
- [18] M. Droese, T. Fujii and M. Tanimoto, "Ray-Space Interpolation Constraining Smooth Disparities Based On Loopy Belief Propagation", *Proc. of IWSSIP2004*, pp. 247-250, Poznan, Poland, Sept. 2004.
- [19] Norishige Fukushima, Tomohiro Yendo, Toshiaki Fujii and Masayuki Tanimoto, "An Effective Partial Interpolation Method for Ray-Space", *Proc. of 3D Image Conference 2006*, pp. 85-88, July 2006.
- [20] M. Sugawara, M. Kanazawa, K. Mitani, H. Shimamoto, T. Yamashita and F. Okano, "Ultrahigh-Definition Video System with 4000 Scanning Lines", *SMPTE Motion Imaging*, 112, pp.339-346, October/November 2003.
- [21] T. Fujii and M. Tanimoto, "Real-Time Ray-Space Acquisition System", *SPIE Electronic Imaging*, vol. 5291, pp. 179-187, Jan. 2004.
- [22] T. Endo, Y. Kajiki, T. Honda and M. Sato, "Cylindrical 3-D Video Display Observable from All Directions", *Proceedins of Pacific Graphics 2000*, pp.300-306, 2000.
- [23] M. Tanimoto, T. Fujii, S. Sakazawa and H. Kimata, "Proposal on Standardization of Free Viewpoint TV (FTV)," *ISO/IEC JTC1/SC29/WG11*, M13612 (JVT-T140), July 2006.



# Color reproduction in the image and video display "beyond RGB"

Masahiro Yamaguchi

Imaging Science and Engineering laboratory, Tokyo Institute of Technology  
4259-R2-56 Nagatsuta, Midori-ku, Yokohama 226-8503  
guchi@isl.titech.ac.jp

## Abstract

*This paper introduces the innovative color reproduction technologies in the display of images and video, going beyond conventional RGB-based systems. In the recent applications of visual communication systems, the image data are utilized in various purposes, such as medical diagnosis, electronic commerce, product design, and image database, and it is expected that the image content faithfully characterize the subject in the image. However, the RGB-based color representation is usually device-dependent, illumination-dependent, and application-specific, and it is difficult to reproduce the original color of subject. The spectrum-based color reproduction is the breakthrough of the RGB-based systems, because it deals with quantitative color information, which enables the high-fidelity color reproduction, the substantial improvement of color accuracy, the expansion of color gamut, and the color reproduction under different illumination environment. In addition, the quantitative color information enhances the value of image data, namely it expands the use of image content. In this paper, after the limitations of current RGB-based systems are addressed, the concept and technologies of spectrum-based color reproduction technology are introduced. The impact to the application is also presented along with the examples of experimental investigations.*

## 1. Introduction

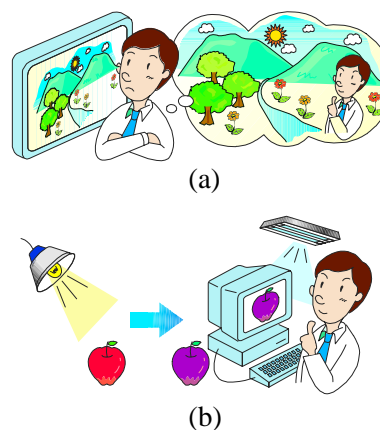
The issue of color is now receiving considerable attention in the applications of image and video technology. The quality of color becomes significantly improved in the recent displays and prints; better color tone, higher color contrast, and wider color gamut. Then it is desired to reproduce more and more realistic image on the advanced high-quality displays. For the realistic image display, the reproduction of the original color, i.e., natural color reproduction, is quite important [Fig.1]. The natural color reproduction is also one of the key issues in the telemedicine, electronic commerce, and electronic museum.

However, the conventional image and video systems do not reproduce the original color of subject, and it obstructs the applications of visual communication systems. The color management technology is greatly progressed especially in color printing, but there still remain limitations imposed by

RGB 3-primary color systems.

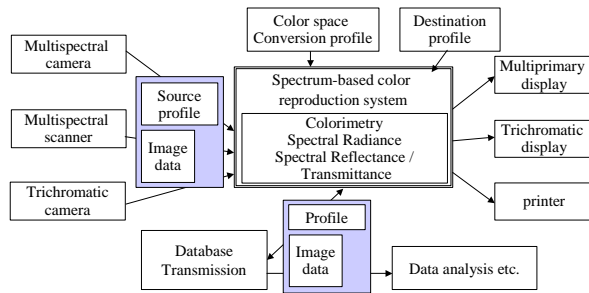
To breakthrough the limitation, there have been reported that the use of multispectral imaging significantly improves the color accuracy [1-4]. Moreover, "Natural Vision" (referred as NV hereafter) system [5-7] has been developed aiming at an innovative video and still-image communication technology, which enables high-fidelity color reproduction, based on spectral information.

NV is an industry-government-academy joint project [5] performed at Akasaka Natural Vision Research Center (NVRC) from 1999 through 2006, conducted by NICT (National Institute of Information and Communications Technology, formally TAO) under the support of the Ministry of Internal Affairs and Communication. Researchers from academic institutes (Tokyo Institute of Technology and Chiba University) and industry (NTT Data, Olympus, NTT, etc.) were participated in the project. The activity of NV is currently being continued. In NV project, the experimental systems for both still-image and video have been elaborated and shown the effectiveness of spectrum-based color reproduction scheme. This paper introduces the motivation, methodology, systems, and applications of spectrum-based color reproduction technology, mainly referring the results of NV project.



**Figure 1:** The concept of natural color reproduction. (a) Reproducing the color as if the observer were at the remote site, (b) reproducing the color as if object were placed at the site of observer,





**Figure 2:** The scheme of spectrum-based color reproduction system

## 2. Limitation of RGB-based systems

Let us briefly review the limitations of conventional RGB-based systems, to make clear the advantage of spectrum-based color reproduction.

- (1) The RGB values obtained in conventional systems often have different meanings, depending on the device characteristics or color processing. For example, many of conventional color imaging systems are designed for user preference, RGB values does not represent the objective color information.
- (2) The spectral sensitivity characteristics of color camera are different from the human vision; RGB signal does not have one-by-one correspondence to the tristimulus values perceived by human vision. If the spectral sensitivity is closer to human vision, the color fidelity is improved, but noise behavior is known to become worse.
- (3) The RGB or any other 3-primary color signals that comply with the color space such as sRGB or YCbCr, which are defined under the white point such as CIE D65 or D50 standard illuminant. To reproduce the color as if the object were placed in the presence of the observer [fig.1(b)], the color under different illuminant is required, but the standard color space does not support the color under arbitrary illuminant.
- (4) For the color reproduction shown in fig.1(b), the spectral reflectance of object and the illuminant spectrum are essentially required for calculating the color under different illuminant. White balance adjustment in RGB space does not give high colorimetric accuracy.
- (5) The color gamut of a normal RGB display is limited, and some of high-saturation colors cannot be reproduced. Even if the display device allows the display of wider color gamut, conventional color signals such as sRGB or ITU-R BT.709 do not support wider gamut color signal.
- (6) The observer metamerism effect, due to the observer dependence of color matching functions, cannot be ignored in high-accuracy color reproduction, ex., in the color proofing of printed materials with color monitors.
- (7) In the image archive, database, or analysis, the utilization of color information is limited, since the RGB signal depends on the devices, illuminants, and preprocesses

involved in the imaging systems. For example in the image retrieval using color information, target object cannot found if the illumination condition is different.

The target of spectrum-based color reproduction is to overcome these problems in the image and video communication systems.

## 3. Spectrum-based color reproduction

The concept of the spectrum-based color reproduction system [6,7] is depicted in fig.2. To obtain sufficient spectral information, multispectral camera (MSC) is desired as an input device. The profile of the input device including the spectral sensitivity, tone curve, and dark current level of the camera, and the spectral energy distribution of illuminant are attached to multispectral image (MSI) data. In image processing, transmission, and storage, the image is accompanied with the profile data, so that the spectral radiance, reflectance or transmittance can be retrieved. In image display, the image of tristimulus values or spectral radiance is reproduced on 3-primary or multiprimary color display with device calibration.

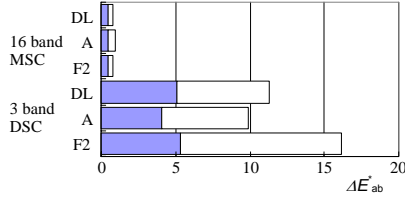
The architecture of spectrum-based color reproduction system is similar to the ICC (International Color Consortium) color management system, but the profile connection space (PCS) is based on physical model, i.e., spectrum-based PCS (SPCS) instead of color appearance model. This can be any of CIEXYZ under arbitrary illumination, spectral radiance, or spectral reflectance. The information required for the transform to SPCS is held in the profile data. The profile data format was defined as NV image data format, which was proposed to CIE TC8-07. The XML version NV format was also developed for easier handling.

In this system, the numbers of channels in the image capture and the display are independent, and the input and output devices with the arbitrary numbers of channels can be employed. Three-channel devices can also be used in this system with proper device characterization, with certain restrictions in the color reproduction capability or accuracy.

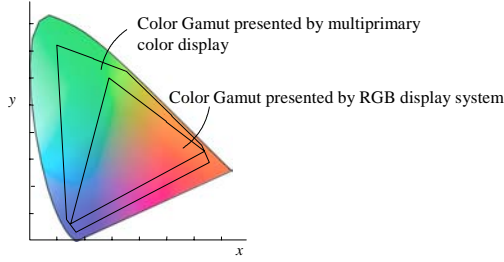
Spectrum-based system offers the solution to the problems presented in the section 2, as follows:

(a) For the natural color reproduction of real scene as if the observer were at the site as shown in fig.1(a), the colorimetric or spectral information is accurately captured and reproduced on a screen.

(b) In the situation shown in fig.1(b), the spectral reflectance of the object is captured and the color under the illumination of observing environment can be reproduced on a screen. Fig.3 depicts the example of color accuracy estimated from the 16-band camera shown in fig.5 and commercial 3-band digital still camera (DSC) with spectral characterization. It shows the advantage of using spectral information for accurate color reproduction.



**Figure 3:** The color estimation accuracy of 16-band MSC and 3-band DSC, evaluated using GretagMacbeth Color Checker, under daylight (DL), CIE A and F2 illuminants, where DL was used in the image capturing.



**Figure 4:** The color gamut obtained by 6-primary color display shown in fig.7 in comparison with conventional RGB display.

**Table 1:** Comparison of color gamut with conventional RGB display and natural objects (Pointer+SOCS gamut [7]).

	Pointer+SOCS	RGB-DLP	6-P DLP [Fig.6(a)]
Volume ( $\times 10^9$ )	0.890	0.908	1.647
Relative volume	1.00	1.02	1.85
Natural color coverage (%)	100.0	78.8	99.2

(c) The wider color gamut becomes available by multiprimary color display, i.e., using more than three-primary colors. Fig.4 and Table 1 show the color gamut obtained by the 6-primary color displays developed by NV project [8,9]. Also, the image and video data obtained from spectrum-based system can represent the wider gamut signal.

(d) The original attribute of object that generates color, ex., spectral radiance, reflectance or transmittance information of the object, is captured and preserved by means of multispectral imaging. Such information is useful for the analysis or the recognition of object, in the digital archives of cultural heritage, artworks, and clinical cases in medicine.

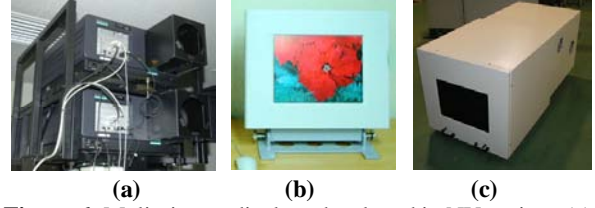
#### 4. Multispectral and Multiprimary Technology

##### Multispectral Image Capture

Fig.5(a) shows the 16-band MSC developed in NVRC. As in fig.3, the accuracy by MSC is high and better than the discriminable level of human vision, while visually apparent error is observed in 3-band DSC. Fig.5(b) shows a 6-band HDTV camera for the acquisition of motion picture [10]. In image capturing, the illumination light spectrum is also measured, and then the spectral reflectance of the object can be calculated using the multispectral pixel value, illumination spectrum, and the spectral sensitivity of the camera.



**Figure 5:** (a) 16-band MSC with rotating filter wheel. (b) 6-band HDTV camera for capturing motion picture.



**Figure 6:** Multiprimary displays developed in NV project. (a) 6-primary DLP projector (b) 4-primary flat-panel LCD display with LED backlight, and (c) 6-primary rear-projection display.

##### Multiprimary color displays and wide gamut systems

Although there were few previous works on multiprimary color displays for larger color gamut [11], the system development and evaluation of multiprimary display had been originally started by NV project. The multiprimary projection displays were developed in NV as shown in fig.6 to confirm the advantage of wide gamut natural color reproduction system and to evaluate its component such as multiprimary color conversion techniques. As in fig.4 and table 1, 6-primary DLP display almost covers the gamut of natural objects and the gamut volume in CIELAB space is about 1.8times larger than the normal RGB projector. The gamut is enlarged in the dark red, cyan, purple regions and bright orange regions. There have been reports of multiprimary displays recently for commercial products from various companies [12,13]

Since the conventional color space for images and video does not cover the whole color gamut, it is required to use expanded color space for wide gamut display. Conventional color spaces are defined according to the narrower gamut color display, but it is not required to depend on the display characteristics in the definition of color space from the aspect of spectrum-based color reproduction. The wide gamut video signal can be directly encoded with CIEXYZ, CIELAB, though the efficiency is not optimized if considering the quantization. Recently, standards for wider gamut video signal become a reality, de facto or de jure, such as ITU-R BT.1361, xvYCC, and adobeRGB. It is expected to establish the content creation environment for wider gamut images and video, and to realize the broadcasting of wider gamut video for the widespread use of the benefit of latest display technology.

##### Spectral color display

There exists variability in color matching functions of

human observers; originated from the macular pigments, lens absorption, and cone sensitivity. Due to the individual difference of color matching functions, the color difference may appear to a certain observer when two color stimuli are shown, even if they are perceived as the same color by another observer, or CIE standard observer, called observer metamerism. It causes the color mismatch between different media, such as color printed materials and displays, even though the colorimetric match is achieved for CIE XYZ values. Based on the multispectral and multiprimary technology, spectral color display becomes possible, and the observer metamerism effect can be disappeared. The advantage of spectral color display was experimentally demonstrated using 6-primary display [14].

### Multiprimary color conversion

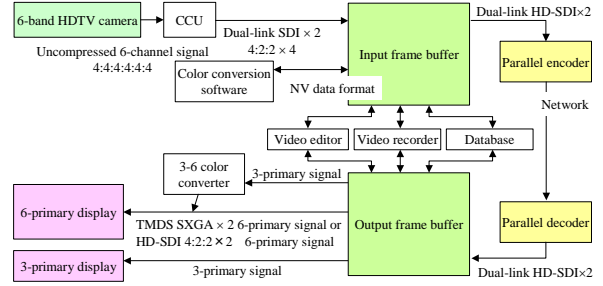
The multiprimary color signal is generated from the image of tristimulus values or multispectral data, called multiprimary color conversion. For colorimetric color reproduction, tristimulus values are transformed to  $M$ -dimensional multiprimary color values (3to $M$ ), where a degree of freedom is involved. Several methods have been developed for 3to $M$  color conversion [15,16]. For the spectral color reproduction explained in the previous paragraph, it becomes  $N$ to $M$  conversion, where  $N$  is the number of channels of MSI. In the proposed  $N$ to $M$  conversion method, the spectral error is minimized under the constraint that the colorimetric match is attained for the standard observer [14].

### Multispectral video system

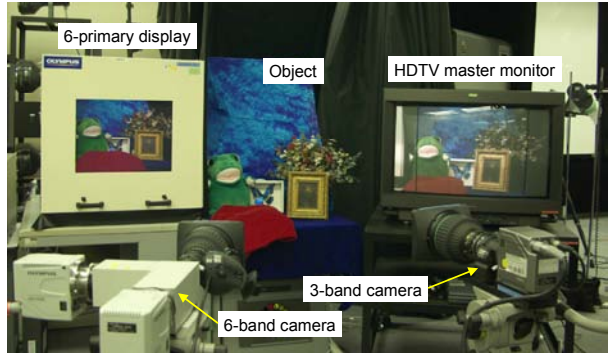
The prototype of the multispectral video transmission was also developed in NV project. By using multiprimary color conversion hardware, real-time colorimetric reproduction is realized with 6-band MSC and 6-primary display in HDTV resolution [7], as shown in figs7 and 8

The compression and encoding are the other issues on MSI transmission. As an MSI compression technique considering the colorimetric accuracy, modified KL transform called weighted KL transform was proposed and combined with JPEG2000 scheme [17]. For video compression, several methods that support multichannel images were tested, including a coding method in which MSI signal is converted into visible and invisible components, considering the compatibility to the conventional video signal [18]. JPEG2000 is one of the suitable formats for high-quality encoding of both video and still MSI's. The profile data for NV format described above can be easily implemented in JPEG2000 as a extended ICC profile or metadata with using XML.

MSI can be considered as a value-added color image, as every pixel has quantitative spectral data. MSI database system has been developed, which supports image processing, analysis, and retrieval that utilize spectral data, and applied to the various fields as explained in the next section.



**Figure 7:** The experimental prototype system for multispectral and multiprimary video reproduction.

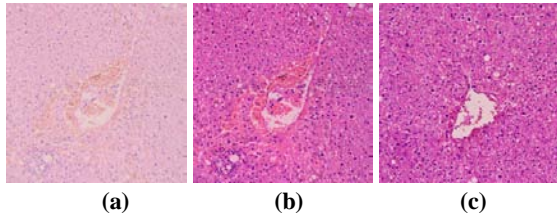


**Figure 8** Experimental live reproduction using 6-band HDTV camera, 6-primary display, and real-time color conversion, comparing with conventional HDTV. Note that the difference can only be seen in the real situation.

## 5. Applications

It is expected that realistic images and video display with high-fidelity natural color reproduction technology will be applied in various fields. There have been experimentally demonstrated the effectiveness of spectrum-based system;

In medicine, the use of digital color images is extremely valuable for teleconference, teleconsultation, education, training, image analysis, and reference database, in pathology, endoscopy, and dermatology. It is also required to reproduce the complexion of a patient through visual communication system for the telediagnosis and homecare. If the reproduced color is not accurate, it may cause misdiagnosis, thus the reliability of reproduced color is critical [19]. In dermatology, MSI systems of both still-image and video were tested and the color reproducibility of multispectral system was rated sufficiently high from the visual evaluation by dermatologists [20]. In the pathology application, the spectrum-based system enables not only the accurate color reproduction of stained specimen, but also the correction of variation in staining condition, with adjusting the amount of stain through digital process [21] [Fig.8]. It was also shown that spectral information is useful for the image analysis that supports diagnosis in both pathology and dermatology; the grading of disorders or the quantitative evaluation of treatments [20].



**Figure 9** Application to pathology: standardization of staining condition. (a) An image of understained specimen, (b) Corrected image from (a), (c) Example of optimal stain.

In the field of electronic commerce (EC), high-fidelity color reproduction is very important. In the online-shopping and trading of textiles, apparels, cosmetics, vehicles, furniture, etc., the color difference causes the return of purchased items. Also in the color matching of samples between designers, factory, buyers, and sales, the quantitative color information is quite beneficial. High-fidelity natural color reproduction system will contribute the further progress in EC. A web-based server-client prototype of electronic catalog system was developed in NV, and its effectiveness was demonstrated.

In the digital archive and electronic museum for art and cultural heritage, it is undesirable that the color of the archive depends on the imaging device and illumination condition with the use of conventional imaging devices. There have been many reports on the multispectral imaging for digital archive. The result of color reproduction on a display using 16-band MSI was shown to be satisfactory for the art management staffs in NV project [22]. The image data can be also employed for the high-fidelity color prints. Moreover, the spectral information in the image will be useful for the analysis of pigments or dyes, or the selection of material for restoration.

As for the application to color prints, it has been also proved that multispectral imaging greatly improves the color fidelity. In the test assuming the printing of catalogs for product promotion, a 16-band MSC and professional RGB DSC's were compared. From the printed images obtained from the RGB DSC, a professional print director put 4-5 instructions for color corrections on average per printed sample. On the other hand, no instruction for color correction was given to any of resultant samples from 16-band MSC. The print director also commented that the printed results from MSI is even better than the proof produced from RGB DSC after the color correction [23]. Furthermore, the spectral color display can be useful for the color proofing applications using softcopy monitors, since the color matching between display and print is considerably improved thanks to the spectral approximation.

Digital prototyping is an important technology for expedition and efficiency of product development, and computer graphics (CG) enables the realistic rendering of virtual products, using Bidirectional Reflectance Distribution

Function (BRDF) or Bidirectional Texture Function (BTF), but the color disagrees with real products. Multispectral BRDF/BTF measurement system and multispectral rendering technique were developed for high-fidelity color digital prototyping [24].

The expanded color gamut provides a new tool or new color for graphics expression. A CG system for coloring with multiprimary colors, named "IRODORI" [25] in NV project. Through the experiences of graphic expression using 6-primary display, the significance of wide-gamut graphics; (a) rendering of reality in vivid or splendid colors, (b) the enhanced reality based on "memory color," which often shifts to higher saturation with time, (c) strong impact or fantastic impression, and (d) rich color tone thanks to the expansion of color range, providing the faint color change with dark colors, or the expression of gloss, metallic colors, or emissive colors.

The application of high-fidelity color reproduction is also beneficial in multimedia education such as instructional materials and encyclopedia, theater or electronic museum for realistic color reproduction of nature, artworks, and historic subjects. It can be also applied to the high-quality color management in the contents production from the material of recorded picture, editing, distribution, and playback of CG, animation, and other visual programs. In NV project, video contents were produced using 6-band HDTV camera and multiprimary CG, and the feasibility of spectrum-based systems was demonstrated. The application to digital broadcasting is strongly expected to facilitate the widespread use of innovative color imaging technology.

## 6. Conclusion

The concept, technology, and applications of spectrum-based color reproduction system are introduced in this paper. It enables not only the high-fidelity color reproduction but also the application of image analysis based on the quantitative spectral information. Moreover, multispectral information will be also of great utility in the image editing for preferable color, and other various image processing such as object extraction or image synthesis, though those were not the main topic of NV project that basically aims to natural color reproduction.

Going beyond RGB, great benefit emerges in advanced imaging applications. Multiprimary printing is already available in commercial product, but to make better use of devices that support innovative color reproducibility, a platform for spectrum-based system is expected, i.e., multispectral and wide-gamut video contents creation, management, distribution, and utilization.

Along with the introduction of information technology into our life, the quality of information that flows through the system becomes very important. For example, the image is used for diagnostic decision in the telemedicine system, and in electronic commerce, purchase or order items based on the digital information including images. If inaccurate images



were presented, it might mislead one's decision. Exchanging objective and accurate information will be more important in our society.

The author acknowledges the former research members of Natural Vision project; Nagaaki Ohya, leader, Hideaki Haneishi, sub-leader, Toshio Uchiyama, Kenro Ohsawa, Hiroyuki Fukuda, Junko Kishimoto, Hiroshi Kanazawa, Tomohito Fujikawa, Hideto Motomura, Tatsuki Inuzuka and Satoshi Nambu, other fellow members from Olympus Co., NTT DATA Co., NTT Co., Toppan Printing Co., Dai-Nippon Printing Co., Matsushita Electric Industrial Co., Hitachi Co., NHK and others, joint researchers of NV project, those co-operating institutes and companies, National Institute of Information and Communications Technology, Ministry of Internal Affairs and Communication, and Natural Vision Promotion Council for the great support in NV project.

## References

- [1] B. Hill, F. W. Vorhagen, "Multispectral image pick-up system," US pat. 5319472 (1994)
- [2] P. D. Burns and R. S. Berns: "Analysis of multispectral image capture," Proc. 4th Color Imag. Conf. 19-22 (1996)
- [3] M. Yamaguchi, R. Iwama, Y. Ohya, T. Obi, N. Ohya and Y. Komiya, and T. Wada, "Natural color reproduction in the television system for telemedicine," Proc. SPIE, 3031, 482-489 (1997)
- [4] M. Rosen, F. Imai, X. Jiang, and N. Ohta, "Spectral Reproduction from Scene to Hardcopy II: Image Processing," Proc. SPIE, 4300, 33-41 (2001)
- [5] Annual reports of Natural Vision Project, FY1999-2003 (TAO), FY2004-2006 (NICT), (2000-2007)
- [6] M. Yamaguchi, T. Teraji, et. al., "Color image reproduction based on the multispectral and multiprimary imaging: Experimental evaluation," Proc. SPIE, 4663, 15-26 (2002)
- [7] M. Yamaguchi, H. Haneishi, et al., "High-fidelity video and still-image communication based on spectral information: Natural Vision system and its applications," Proc. SPIE, 6062, 60620G (2006)
- [8] T. Ajito, T. Obi, M. Yamaguchi, and N. Ohya, "Expanded color gamut reproduced by six-primary projection display," Proc. SPIE, 3954, 130-137 (2000)
- [9] H. Motomura, N. Ohya, M. Yamaguchi, H. Haneishi, K. Kanamori, S. Sannohe, "Development of Six-Primary HDTV display system," Proc. Int. Display Research Conference, 563-566 (2002)
- [10] K. Ohsawa, T. Ajito, H. Fukuda, Y. Komiya, H. Haneishi, M. Yamaguchi, and N. Ohya, "Six-band HDTV camera system for spectrum-based color reproduction," J. Imag. Sci. and Tech., 48, 2, 85-92 (2004)
- [11] R. Yajima, M. Kanazawa, and S. Sakaida, "Wide-color-gamut system," ITE '94 Annual convention, 355-356 (1994) (in Japanese)
- [12] S. Roth, I. Ben-David, M. Ben-Chorin, D. Eliav, and O. Bben-David, "Wide gamut, high-brightness multiple primaries single panel projection displays," SID '03 Digest 118-121 (2003)
- [13] M-C. Kim, Y-C. Shin, Y-R. Song, S-J. Lee, and I-D. Kim, "Wide gamut multi-primary display for HDTV," Proceedings of CGIV 2004, 248-253 (2004)
- [14] Y. Murakami, J. Ishii, T. Obi, M. Yamaguchi, and N. Ohya, "Color conversion method for multi-primary display for spectral color reproduction," J. Electronic Imaging, 13, 4, 701-708 (2004)
- [15] T. Ajito, K. Ohsawa, T. Obi, M. Yamaguchi, and N. Ohya, "Color conversion method for multiprimary display using matrix switching," Opt. Rev., 8, 3, 191-197 (2001)
- [16] H. Kanazawa, "Color conversion for multiprimary displays using a spherical average method," Proc. 12th Color Imag. Conf., 65-69 (2004)
- [17] S. Yu, Y. Murakami, T. Obi, M. Yamaguchi, and N. Ohya, "Multispectral image compression for high fidelity colorimetric and spectral reproduction," J. Imag. Sci. and Tech., 50, (1): 64-72 (2006).
- [18] S. Takamura and N. Kobayashi, "Constructing a uniform color space for visually lossless color representation and image coding," IEEE International Conference on Image Processing, 918-921 (2001)
- [19] T. Numahara, "From the standpoint of Dermatology," in Digital Color Imaging in Biomedicine, H. Tanaka, Y. Miyake, M. Nishibori, and D. Mukhopadhyay, eds., Digital Biocolor Society, 67-72 (2001)
- [20] M. Yamaguchi, et al., " Multispectral color imaging for dermatology: application in inflammatory and immunologic diseases," Proc. 13th Color Imag. Conf., 52-58 (2005)
- [21] T. Abe, Y. Murakami, M. Yamaguchi, N. Ohya, and Y. Yagi, "Color correction of pathological images based on dye amount quantification," Opt. Rev., 12, 4, 293-300 (2005)
- [22] H. Fukuda, T. Uchiyama, H. Haneishi, M. Yamaguchi, and N. Ohya, "Development of 16-bands multispectral image archiving system," Proc. SPIE, 5667, 136-145 (2005)
- [23] A. Uchida, et al., "Product photography for catalogs with multispectral camera," Proc. of Spring Conf. of the Japanese Society of Printing Science and Technology, 131-134 (2003) (in Japanese)
- [24] M. Tsuchida, et. al., "Development of BRDF and BTF Measurement and Computer-aided Design Systems Based on Multispectral Imaging," Proc. AIC Colour '05 129-132 (2005)
- [25] J. Kishimoto, M. Yamaguchi, H. Haneishi, and N. Ohya, "IRODORI - A Color-rich Palette Based on Natural Vision Technology-," ACM SIGGRAPH 2004 Emerging Technology (2004)

# Electronic Paper: Display for Comfortable Reading

## - A Study on effects of media handling styles -

*Makoto Omodani*

*Department of Optical and Imaging Science & Technology, Tokai University*

*1117 Kitakaname, Hiratsuka, Kanagawa, 259-1292, JAPAN*

### Abstract

*The development of electronic paper, which has the merits of both paper and electronic displays, is being eagerly pursued. This study aims to clarify the factors of readability which is naturally realized by paper; clarified factors will yield good guidelines for realizing readable electronic paper. Our expectation is that reading style is an important factor determining readability. We evaluate the reading performance of three medium handling styles (vertical, horizontal, hand-held) using current electronic books (LIBRIe, ΣBook) and paper documents. Test results show, for both types of electronic books, that the "hand-held" style is superior in terms of lower fatigue and better readability. It is suggested that the readability of electronic displays can be enhanced by making them compact and permitting the hand-held reading style.*

### 1. Introduction

Electronic paper, which should provide the advantages of both paper and electronic displays (Fig. 1), is a prime research topic.<sup>1,2</sup> This study aims to clarify the factors of readability with regard to paper; these factors will yield good suggestions for realizing readable electronic paper. Several reports presented on the factors of readability have examined medium angle<sup>3</sup>, medium form<sup>4</sup>, contrast<sup>5</sup>, lighting condition<sup>6</sup> etc. However, it is not clear how to assess these factors. We are attempting to clarify the causes of the difference in fatigue levels seen for two kinds of media: paper and electronic displays (displays hereafter). One possible cause is the difference in reading styles. "Freehand holding" is a popular way of reading text on paper, and this reading style is totally different from the fixed reading style provided by displays on desks.

We have already reported a comparison of readability and fatigue level of reading tasks on paper and on displays. We have confirmed that freehand holding increases readability and reduces fatigue levels especially for displays.<sup>7-9</sup> This study aims to reconfirm that the "hand-held" condition is advantageous for reducing

fatigue and enhancing readability. Reading performances were evaluated for different medium handling styles using current electronic books (LIBRIe, ΣBook) and paper. The Analytic Hierarchy Process<sup>\*</sup> (AHP) was used for this subjective evaluation.<sup>10, 11</sup>

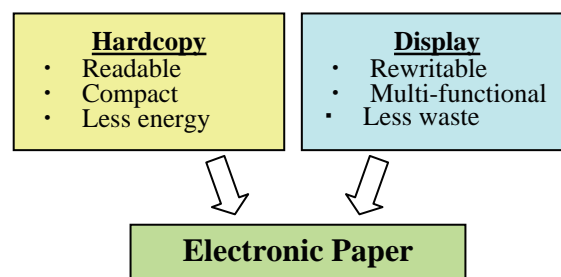
### 2. Experiments

#### 2.1 Experimental Method

Experiments were carried out in order to evaluate fatigue levels (eyes or body) and readability under various reading styles using current electronic books (LIBRIe, Σbook) and paper. Three different reading styles were examined: vertical (the medium was set on a desk (A)), horizontal (the medium was laid on a desk (B)), and hand-held (C).

Figure 2 shows the reading scenes as combinations of the three reading styles and the three media. The subjects were presented with material from a Japanese novel and the volume of text read in a 30 minute period was measured. Fatigue levels were assessed from the subjects' responses collected just after each reading task. The tasks were spaced at 15 minute intervals.

Table 1 lists the specifications of the three media. Table 2 shows experimental conditions. Table 3 gives the instructions provided to the subjects.



**Figure 1. Concept of Electronic Paper**

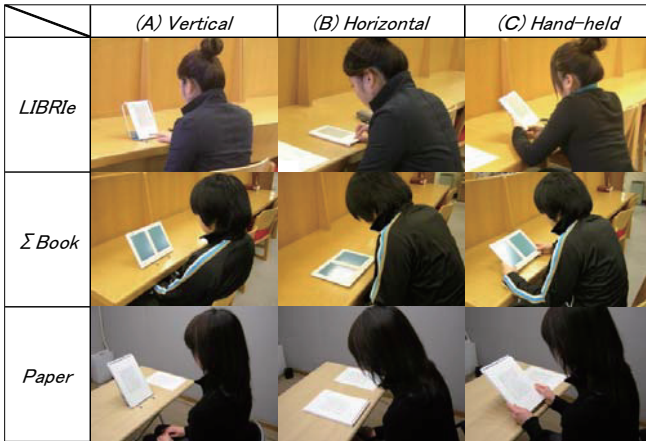


Figure 2. Scenes of Evaluations

Table 1. Media used in evaluations

Mediums	Weight	Picture size
LIBRle	300g	6 inch: SVGA
Σ Book	560g	7.2 inch: XGA
Paper	360g	B5 size (lengthways) 80 sheets on board

Table 2. Evaluation conditions

	LIBRle	Σ Book	Paper
Number of subjects	6	6	6
Subjects	Male and female students, Age: 18-24		
Place	Sound-proof room		
Illumination	800 lx (on the desk plane)		

Table 3. Instructions to subjects

Reading styles	Direction for subjects
Horizontal	Put a medium against the stand on the desk. You may initially adjust the angle as you like
Vertical	Place a medium flat on the desk.
Hand-held	Hold a medium in your hand

## 2.2 Evaluations Method

Subjects were requested to answer three evaluation items: 1) eye fatigue, 2) body fatigue (except eyes), 3) readability.

First, subjects were asked to rate the importance of the three evaluation items: (1) to (3). Next, the subjects were presented with one medium and used it in the three reading styles: A to C. Last, subjects were requested to evaluate the effect of the three reading styles.

The score of each subject was calculated by multiplying the following two elements: their initial importance rating given to the three evaluation items (1) to (3), and evaluated scores of the three evaluation items. Final score for each reading condition was gained by averaging the scores of each subject.

All the evaluations were carried out using the method of comparing pairs of reading styles. Evaluation result for each reading style was calculated using the three sets of comparison results. Figure 3 shows the evaluation scale used in all comparisons between each pair of evaluation items and each pair of reading styles. Names of objects to be evaluated are written at the ends of the scale: i.e. the positions of “object 1” and “object 2” in Fig.3.

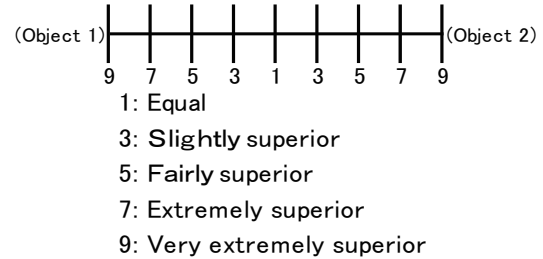


Figure 3. Scale and indexes used in evaluations

A typical example of evaluation sequence is as follows.

### Step 1 <Rating to evaluation items>

Table 4 shows a typical answer provided by a subject and used for rating evaluation items. The subject was required to answer only three values in the table, the other values were determined from the three entered values automatically. Table 4 was then transformed into a 3 by 3 matrix, see Fig. 4. Eigenvectors were calculated from the matrix. These eigenvectors indicate the subject's own rating for three evaluation items.

The rating of this subject was thus calculated as follows: [eye fatigue, body fatigue, readability] = [0.28, 0.33, 0.39]. This result shows that this subject gave most importance to readability.

Table 4. A typical answer

	Eye Fatigue	Body fatigue	Readability
Eye fatigue	(1)	3	(1/7)
Body fatigue	(1/3)	(1)	3
Readability	7	(1/3)	(1)

$$\begin{pmatrix} 1.00 & 3.00 & 0.14 \\ 0.33 & 1.00 & 3.00 \\ 7.00 & 0.33 & 1.00 \end{pmatrix} \Rightarrow \begin{pmatrix} 0.28 \\ 0.33 \\ 0.39 \end{pmatrix}$$

Rating matrix for evaluation items      Eigenvector

Figure 4. Calculation of eigenvectors with a 3 by 3 rating matrix for evaluation items

### Step 2 <Evaluation of reading styles>

Subjects were instructed to read the material in the three reading styles, and then compare the three pairs of three reading styles. The evaluation process of Fig. 2 was applied to their answer. Table 5 shows a typical evaluation result for the three reading styles. Table 5 was



transformed into three matrixes; eigenvectors were calculated as shown in Fig.5.

**Table 5. A typical evaluation result for the three reading styles**

<i>Eye fatigue</i>		<i>Vertical</i>	<i>Horizontal</i>	<i>Hand-held</i>
	<i>Vertical</i>	(1)	5	(1/9)
	<i>Horizontal</i>	(1/5)	(1)	(1/9)
	<i>Hand-held</i>	9	9	(1)
<i>Body fatigue</i>		<i>Vertical</i>	<i>Horizontal</i>	<i>Hand-held</i>
	<i>Vertical</i>	(1)	3	(1/5)
	<i>Horizontal</i>	(1/3)	(1)	(1/9)
	<i>Hand-held</i>	5	9	(1)
<i>Readability</i>		<i>Vertical</i>	<i>Horizontal</i>	<i>Hand-held</i>
	<i>Vertical</i>	(1)	5	(1/7)
	<i>Horizontal</i>	(1/5)	(1)	(1/9)
	<i>Hand-held</i>	7	9	(1)

$$\begin{pmatrix} 1.00 & 5.00 & 0.11 \\ 0.20 & 1.00 & 0.11 \\ 9.00 & 9.00 & 1.00 \end{pmatrix} \rightarrow \begin{pmatrix} 0.17 \\ 0.06 \\ 0.77 \end{pmatrix}$$

$$\begin{pmatrix} 1.00 & 3.00 & 0.20 \\ 0.33 & 1.00 & 0.11 \\ 5.00 & 9.00 & 1.00 \end{pmatrix} \rightarrow \begin{pmatrix} 0.18 \\ 0.07 \\ 0.75 \end{pmatrix}$$

$$\begin{pmatrix} 1.00 & 5.00 & 0.14 \\ 0.20 & 1.00 & 0.11 \\ 7.00 & 9.00 & 1.00 \end{pmatrix} \rightarrow \begin{pmatrix} 0.19 \\ 0.06 \\ 0.75 \end{pmatrix}$$

Evaluation matrix for reading styles      Eigenvector

Figure 5. Calculation of eigenvectors from a 3 by 3 matrix for evaluation of reading style

### Step 3 < General evaluation >

The eigenvectors for each evaluation item in each reading style were transformed into a 3 by 3 matrix. The general evaluation was obtained by multiplying this matrix by the rating matrix as shown in Fig.6. For this subject, the result of general evaluation is as follows: [vertical, horizontal, hand-held] = [0.18, 0.06, 0.75]. This result indicates that the hand-held style is the most favored reading style for this subject. The same procedure was used for all subjects.

$$\begin{pmatrix} 0.17 & 0.18 & 0.19 \\ 0.06 & 0.07 & 0.06 \\ 0.77 & 0.75 & 0.75 \end{pmatrix} \begin{pmatrix} 0.28 \\ 0.33 \\ 0.39 \end{pmatrix} \rightarrow \begin{pmatrix} 0.18 \\ 0.06 \\ 0.75 \end{pmatrix}$$

Matrix of reading styles      Rating      General evaluation

Figure 6. Calculation of general evaluation

## 3. Experimental results

### Results at the electronic books

Figures 7 and 8 show the evaluation results for the electronic books, LIBRlE and Σbook, respectively.

Both yielded the same tendency, the hand-held" style received the highest scores, while "vertical" and "horizontal" styles got quite low scores.

### Results for paper

Figure 9 shows the evaluation results for paper. Differences between the three reading styles are not as large as is true with the electronic books. The hand-held style and the vertical style are slightly superior to the horizontal style.

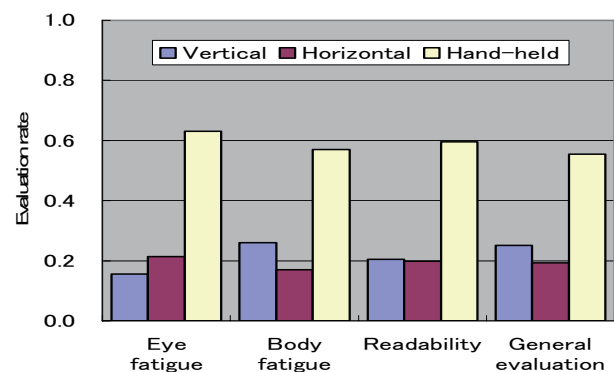


Figure 7. Evaluation results for LIBRlE

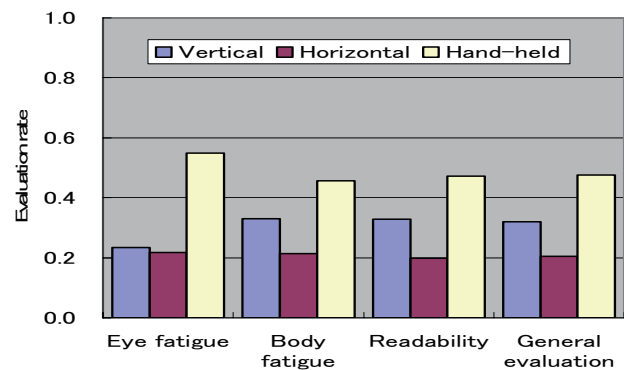


Figure 8. Evaluation results for Σbook

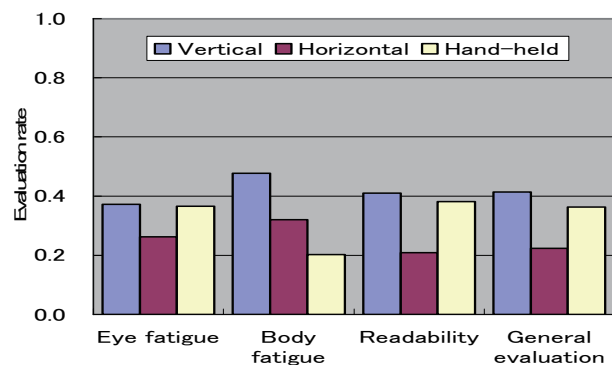


Figure 9. Evaluation results for paper

## 4. Discussion

We have confirmed the advantage of hand-held style in the two electronic books examined. This result is reasonable because the “hand-held” style is the most popular way for us to read books. It indicates why people do not like to read on displays.

Paper, on the other hand, showed no significant advantage for the hand-held style. The prominent advantage of hand-held style shown at electronic books is reasonable when we consider the viewing angle dependence of readability assumed at the electronic books. Hand-held style is the easiest style for us to adjust the angle of a medium to the best condition to read. The universal readability of papers independent to viewing angle is not supposed to request fine adjustment of its angle; the advantage of hand-held style may not be clear at papers. Thus, we consider that the result at papers indicates the next stage of goal for electronic books: universal readability independent of reading styles.

We also consider that the light weight and compact shape of the two electronic book terminals, which enabled the subjects to use the hand-held reading style, greatly improved their general attractiveness as a reading medium; this is ascribed to their ability to freely alter the viewing angle<sup>12</sup>.

## 5. Conclusion

- 1) We confirmed that the "hand-held" reading style increases readability and reduces fatigue levels for the electronic book units of LIBRIe and  $\Sigma$ Book.
- 2) It is suggested that compact medium design that allows the hand-held reading style can improve the readability of electronic displays.

## References

1. M.Omodani: “Concept of Digital Paper and its Technology Trend”, Journal of the Imaging Society of Japan Vol.38, No.2, pp.115-121 (1999).
  2. M.Omodani: “What is Electronic Paper: The Expectations”, SID 2004 Digest, pp.128-131 (2004).
  3. K.Masuda, M.Omodani, Y.Takahashi: “Comparison of human processing faculty for same tasks on visual display and hardcopy”, Journal of the Imaging Society of Japan Vol.129, pp.159-165 (1999).
  4. M.Koshimizu, D.Tsuda, K.Baba: “Form Factors required for Electronic Paper Media”, IEICE Technical Report Vol.25, No.10, pp.19-24 (2001).
  5. K.Sakuragi, M.Omodani: “Contour Mapping of Readability of Hardcopies on the Plane of Optical Density: Characters and Background –A Guideline for Designing Electronic Paper–”, IS&T’s NIP20, pp.369-372 (2004).
  6. M.Kawakami, S.Matsumoto, O.Myodo: “Reasonable Lighting Factors for Working Environment in VDT Work Activities”, Journal of The Illuminating Engineering of Japan Vol.83, No.5, pp.326-331 (1999).
  7. S.Okano, M.Omodani: “Study of Readability as a Target of Electronic Paper ~Effect of media handling styles on reading tasks~”, Japan Hardcopy 2004, pp.193-196 (2004).
  8. S.Okano, M.Omodani, N.Nakata, M.Maeda: “Study of Readability as a Target of Electronic Paper ~Effect of media handling styles on reading tasks~”, IEICE Technical Report, pp.13-16 (2005).
  9. M.Omodani, S.Okano, E.Izawa, A.Sugiyama: “Studies on Readability as a Target of Electronic Paper –Current results and suppositions brought by reading experiments on displays and papers–”, Journal of the Imaging Society of Japan Vol.44, No.2, pp.121-129 (2005).
  10. K.Kasahara: “The Analytic Hierarchy Process Decision Methodology: Evaluation of Continuing Professional Development Point”, Journal of IEICE Vol.88, No.3, pp.200-207 (2005).
  11. T.L.Saaty, L.G.Vargas: “Models, Methods, Concepts & Applications of the Analytic Hierarchy Process”, Kluwer Academic Publishers, pp.1-26 (2001).
  12. S.Okano, M.Omodani, “A Study on Readability as a Goal of Electronic Paper - Effects of media handling styles -”, IS&T’s NIP21 Conference, pp.65-68 (2005).
- 
- . \* Analytic Hierarchy Process (AHP) has been developed by T.L.Saaty (University of Pittsburgh) for a method of decision making to choose the best solution among alternatives. AHP method is based on comparisons between all possible pairs among all the alternatives. Comparisons between several viewpoints for evaluations are the first step of the AHP method; ratings for the viewpoints are gotten in this step. This step is followed by comparisons between all the alternatives. The results of ratings are taken into account for general evaluations at the final step. The comparison performed between pair of alternatives is considered to bring us accurate sensitivity.

# Panel Discussion

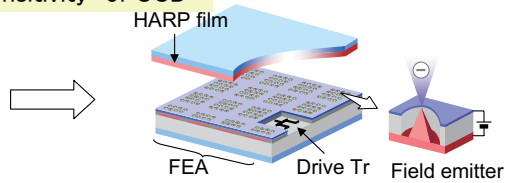
## Some topics of Image capturing & Program production(1)

### <Image capturing>

- Super high sensitivity: 200 times sensitivity of CCD



Hi-Vision HARP camera tube



Field emitter array HARP image sensor

- Super high-speed camera: 1,000,000 F/S max & high sensitivity



Burst of water balloon  
(Frame rate: 16,000 F/S)

Kenkichi Tanioka



## Some topics of Image capturing & Program production(2)

### <Image capturing>

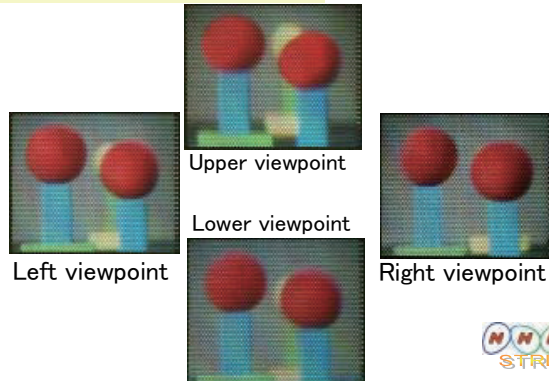
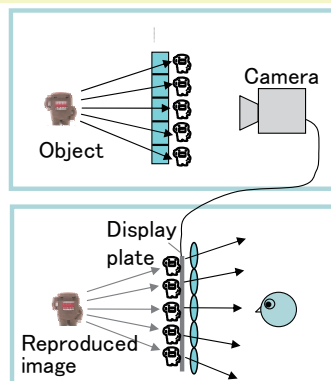
- Super Hi-vision: Extremely high resolution

-4320 × 7680 pixels  
-60fps

Applications  
for HDTV



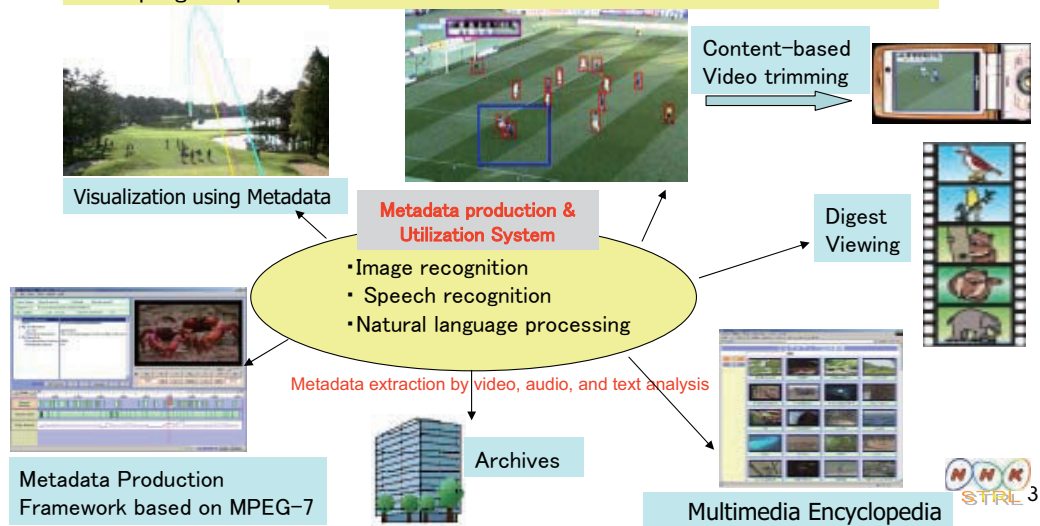
- Super parallel spatial 3-D imaging: Three-dimensional TV



## Some topics of Image capturing & Program production(3)

### <Program production>

Metadata production to use broadcast content for a variety of services and make program production efficient

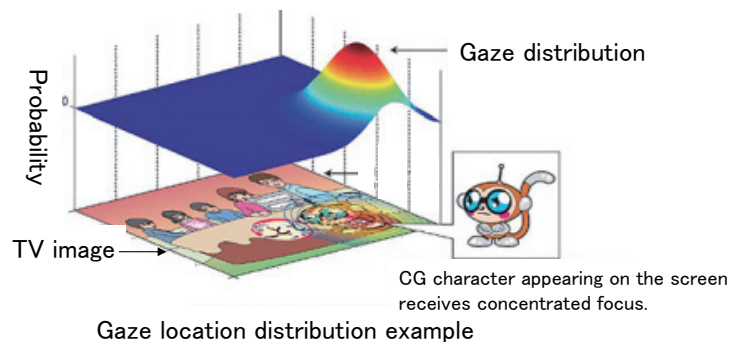


## Some topics of Image capturing & Program production(4)

### <Program production>

#### • Content quality estimation technology

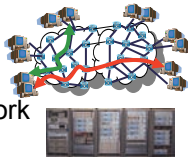
- The relationship between someone's gaze while viewing a program and their comprehension of the content.
- Analyzed the movements of their gazes for 28 elementary school children.
- Concentrate on the text in the images (telop) and on a CG character.



## New Research Department of NICT

### Research Department 1 New Generation Network

- New Generation Network
- New Generation Wireless
- Future-oriented ICT Network



Network infrastructure that enables information exchange anytime, anywhere, and anyhow

### Research Department 2 Universal Communication

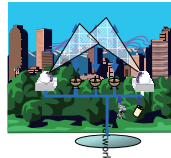
- Natural Communication
- Universal Contents
- Universal Platform
- Common Reality



More friendly, more really, and more freely.  
We open up a world of new communication and sensation with universal technology.

### Research Department 3 ICT for Safety and Security

- Information and Communications Security
- Social Environment Safety with ICT
- Safe and Secure Foundations for Electromagnetic Waves Applications



Establishment of safety and security for secure information exchange and in preparation for disasters a dangers

***Yuichi Matsushima***

**NICT**  
National Institute of  
Information and Communications Technology

## Universal Media Research Center

**NICT**

### “Watching, Listening, Touching and Smelling” - Ultra reality at your side

The center plays pioneering role in the evolution of media technology, realizing ultra-realistic communication system by multisensory data transmission technology and creating new communication infrastructure that provides natural and real information to everybody.

#### ➤ 3D spatial image and sound technology

Holographic 3D video system, 3D sound field reproduction  
System integration for realization of ultrarealistic communication environments

#### ➤ Human perceptual and cognitive mechanisms

Necessary requirements for ultrarealistic systems based on underlying principles of human information processing

#### ➤ Multisensory interfaces

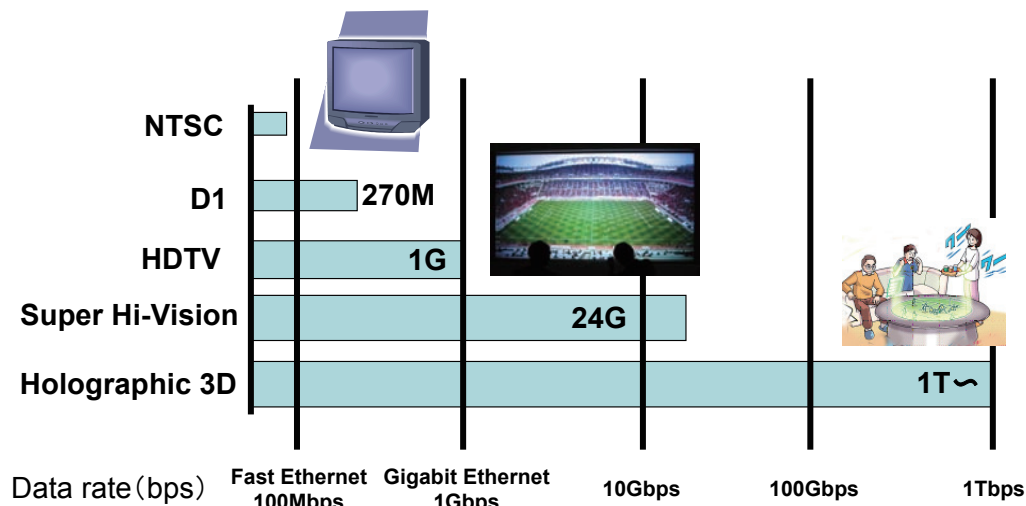
sensing/transmission/display and integration of visual, auditory, tactile and smell information



3D video system and multisensory ultrarealistic communication system to be realized by 2020

## Required Data Rate for Video and Sound Transmission

**NICT**



## Optical Network R&D Promoted by NICT

**NICT**

### From basic research to applied research

#### Research on optical packet switching networks

We have developed the world's first prototype of optical packet routing switch

#### Research promote on ultra-fast communication systems

We promote research on highly-efficient optical communication systems at more than 160 Gbit/s per wavelength. We have exploited the JGN2 optical test bed and also have promoted inspection tests in the field

#### Research on Lambda GRID networks

High performance wavelength (lambda) path networking for distributed processing system (GRID) is being studied

#### Tera-bit class high-capacity optical network technology

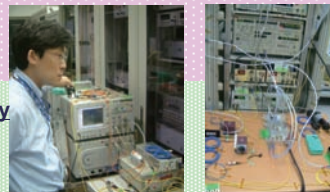
- Optical network technology applied and managed by GMPLS
- Technology for the architecture/application of tera-bit class networks
- Optical access/core network technology
- Optical burst switching technology

#### Giga-bit network for R&D (JGN2)

- 20/10 Gbit/s backbones performed by the OXC/WDM network
- 63 access points nationwide
- Connection with overseas
- Optical test beds are provided in two sights for inspection research



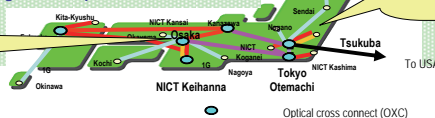
The world's first optical packet switch, developed by a research team at NICT



Inspection testing scene at JGN2 optical test bed sections (at Otemachi access point)

Optical test bed (A)  
Keihanna—Osaka 63km  
(NZ-DSF & SMF X 20Core)

Optical test bed (B)  
Otemachi—Tsukuba 100km (SMF X 2Core)



Legend:  
20G  
10G  
1G  
Dark Fiber



## Limits and Opportunities of "Keitai"

**Minoru Etoh**  
**Research Laboratories, NTT DoCoMo**

**Prospects:** Deployment of Broadband Mobile Networks (up to Mbps) by 2010 -> Incubation Environment of Killer Applications

### Limits in Visual Applications:

Battery, Power Consumption as Vital Issues

Display Devices, QVGA(320 × 240pels) , VGA and more?

### Opportunities toward Future:

Wearable/Detached Interfaces

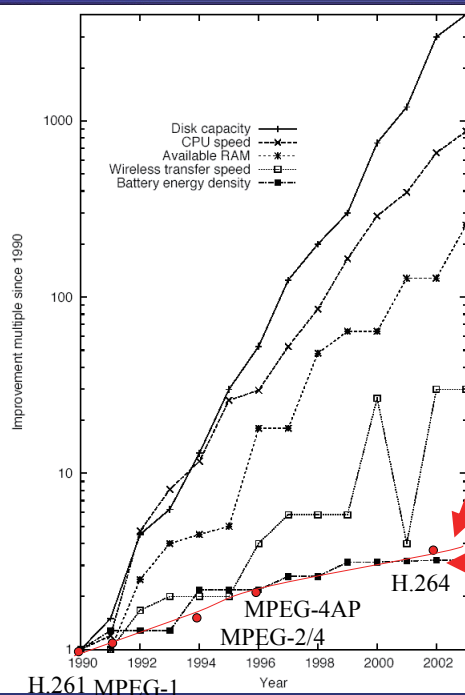
Low Power DSP, Graphic LSI, CODEC

Distribution of Personal Content, Anywhere and Anytime.

1

NTT DoCoMo

## Moore's Law vs. Battery Capacity & CODEC



**CPU Speed**

Double per 18 months

**Video Compression Efficiency**

Triple per 12 years: H.261(1.0) --> MPEG-1(1.25) --> MPEG-4/MPEG-2 (1.75) --> MPEG-4 ASP (2.2) --> H.264 (3.0)

**Battery Energy Density**

Double per 12 years.

2

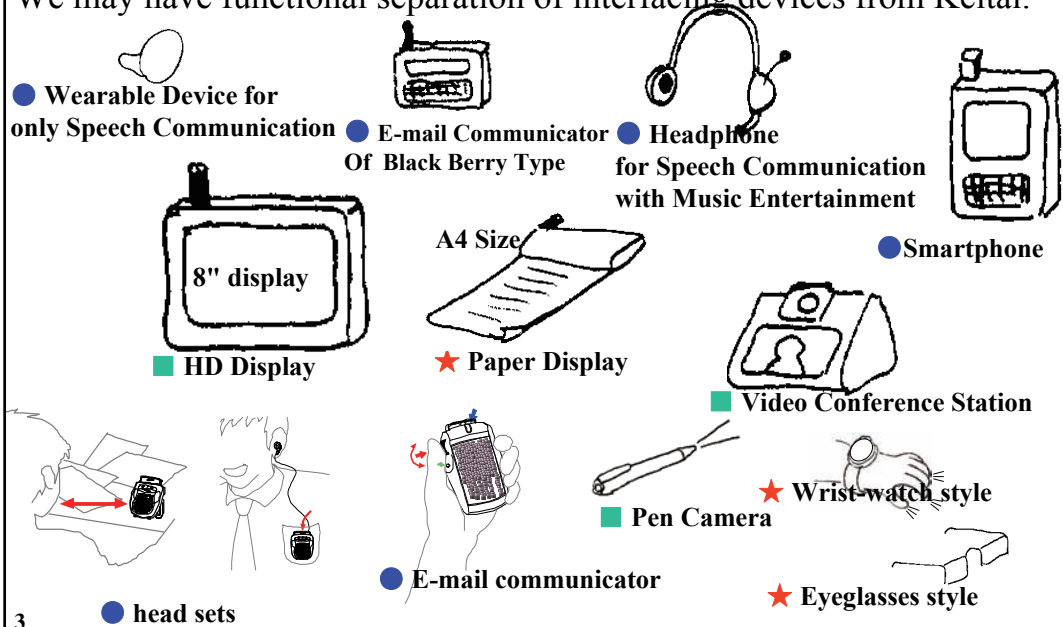
H.261 MPEG-1

NTT DoCoMo



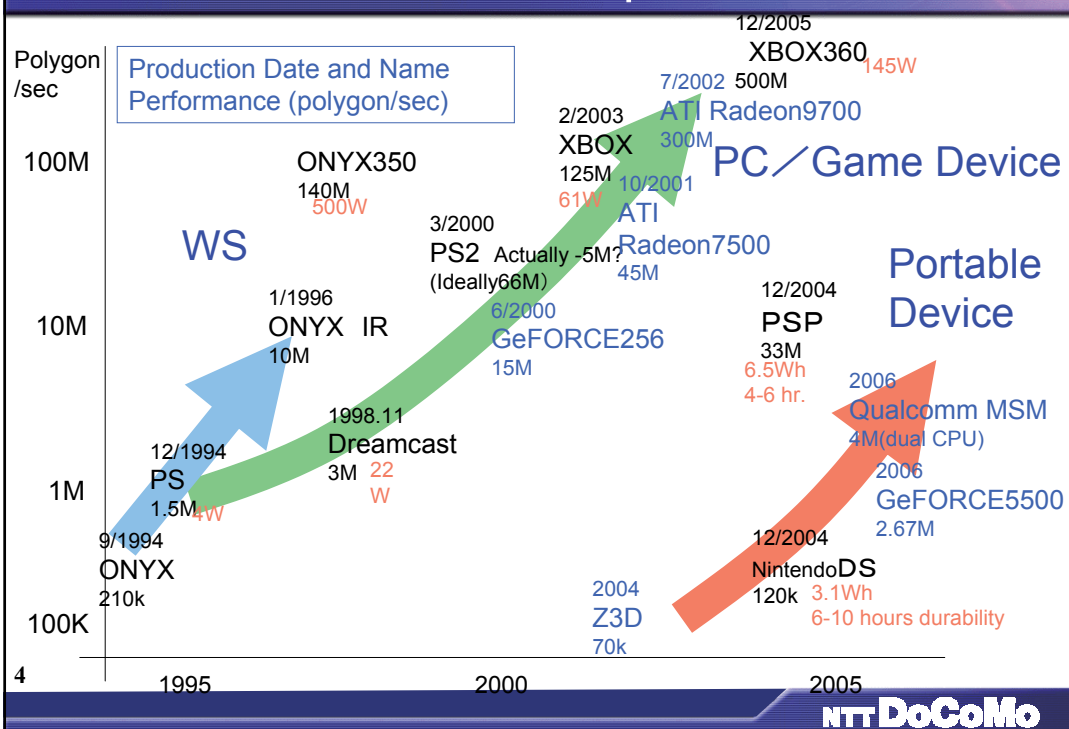
## Keitai as Communication Platform and Connected Interface Devices

We may have functional separation of interfacing devices from Keitai.



NTT DoCoMo

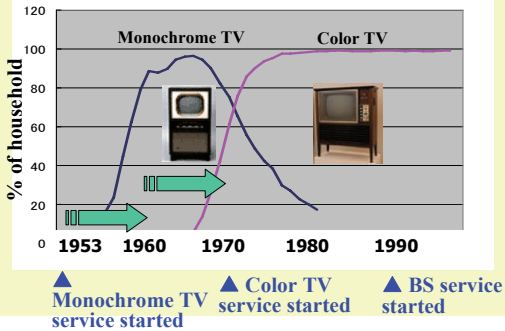
## Evolution of 3D Graphic LSI



## Trend (1): TV broadcasting & TV set

### ■ New Services bring new TV devices into market.

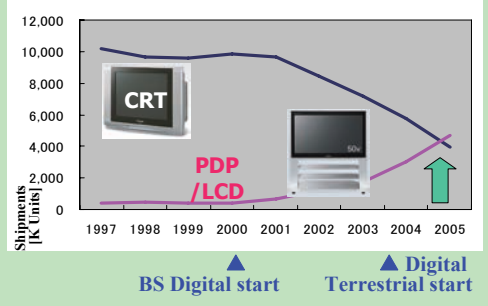
#### Monochrome and Color



**80%** penetration in **10 years**  
since the services started

Monochrome TV: 1953 -> 1960(80%)  
Color TV: 1960 -> 1974(86%)

#### Digital and Flat Panel TV



Flat Panel TV : **20%** penetration in 2005

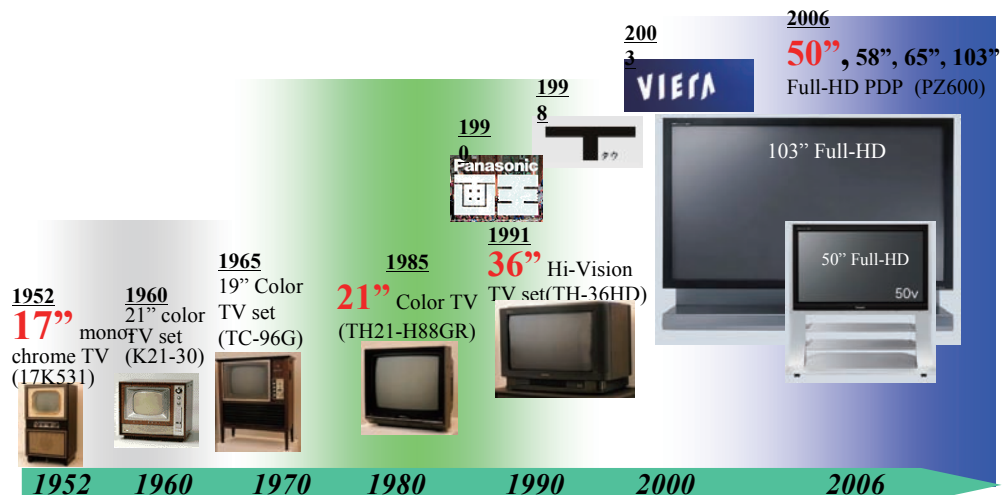
Flat panel TV : 5 million units  
CRT TV : 3.4 million units

Panasonic ideas for life

Kazuo Okamura Matsushita/Panasonic - 1

## Trend (2): Screen Size

### ■ HD Broadcasting has made TV screens larger.

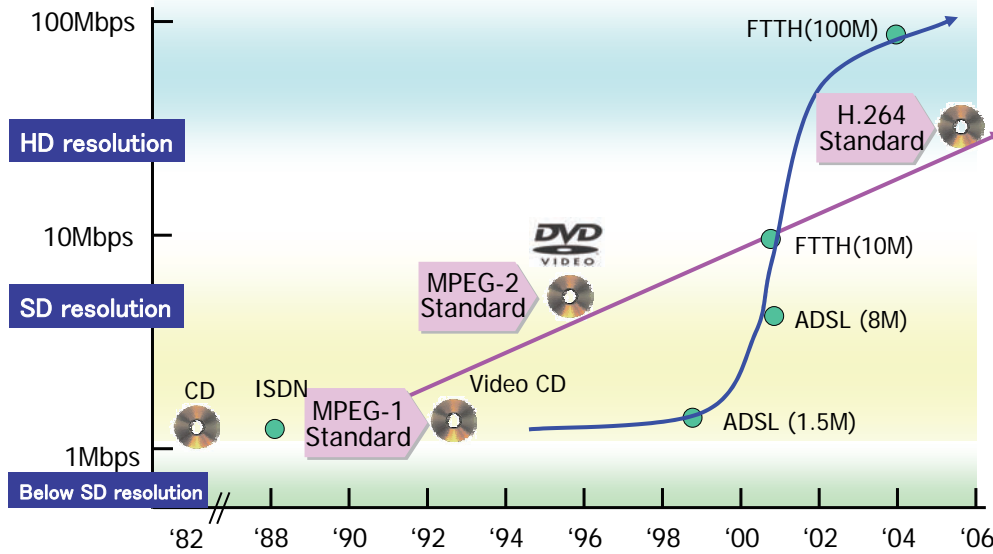


Panasonic ideas for life

Kazuo Okamura Matsushita/Panasonic - 2

### Trend (3): Storage Media

- Progress of storage media and video codec has lead the changes of content format.



### Discussion points

- How bigger? How finer?
  - More than 50 inch ? 4Kx2K, 8Kx4K ?
- Will Internet change the way we watch the TV?
  - IP network infrastructure is becoming ready for video.
- What will be the role of storage media ?
  - HD package contents will be available pretty soon.

## **Environmental Issues in LCDs**

### **3R (Recycle, Reduce, Reuse) Oriented R&D and Manufacturing of Liquid Crystal Displays**

**Shunsuke Kobayashi**

•Liquid Crystal Institute and the Graduate School of  
Science and Engineering  
Tokyo University of Science, Yamaguchi

•JSPS 130<sup>th</sup> Committee of Optoelectronics

*LCI, TUS-Y*

### **3R (Recycle, Reduce, Reuse) Oriented R&D and Manufacturing in LCDs**

1. Prime Minister of Japan Mr. Jun-ichiro Koizumi suggested “3R Initiative” in 2004 at Sea Island Summit.
2. Kyoto Protocol for Reducing CO<sub>2</sub> Exhaustion came into effect on January 15, 2006.
3. RoHS (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment) was enacted on July 1, 2006 on Hg, Cd, and others in EU.
4. Collecting and recycling systems for home appliances (TVs, Refrigerators, Air Conditioners) and personal computers have started since July, 2005 in Japan.

We have to comply with the legislation of electrical and electronic products issued by individual government.

*LCI, TUS-Y*

## Reduction of Power Consumption in LCDs Using Nanoparticle Technology

3

Almost all the physical properties of existing materials will be modified by doping nanoparticles.

For example:

polymer film + nanoparticles → optical properties changes

- Improvement of the power consumption of back lights for LCDs that dominate 70%~80% of total power consumption can be done by the enhancement of luminous efficiency of phosphors and LEDs by using nanoparticles. 40inch LC-TV 120W(CCFL) and 360W(LED)
- 2. Reduction of power consumption of LCDs
  - A) Field sequential fullcolor LCDs will realize the reduction of their power consumption by 30%~50%.
  - B) Reduction of operating voltage of LCDs will be realized by 25%~40% by doping nanoparticles.

*LCI, TUS-Y*

## Reduction of Power Consumption in the Manufacturing of LCDs

4

The sizes of LCDs spreads from those for mobile phones, personal computers and to TV having 45 inch to 60 inch diagonal.

Examples:

- 1) One drop filling (ODF) technology reduces the time for filling LCs into LCD cells by 100 times.
- 2) Caret free glass cutting using lasers reduces the time for glass cutting by 50 times.  
These technologies are being utilized for 8G (2200 × 2500mm<sup>2</sup>) LCD production.
- 3) Doping nanoparticles into individual material for LCD production will be usefull for reducing power consumption.

Conclusions

- 1) We have to obey laws for environmental issues.
- 2) Nanoparticle and laser technologies are useful for reducing power consumption in LCDs themselves and their manufacturing.

Thank you for listening

*LCI, TUS-Y*

# Committee Member

## General Chair

Yasuharu Suematsu, NII (National Institute of Informatics)

## Vice-Chair

Shunsuke Kobayashi, Tokyo University of Science, Yamaguchi  
Yuichi Matsushima, NICT (National Institute of Information and  
Communication Technology)

## Steering Committee Chair

Kazumasa Enami, NHK (Japan Broadcasting Corporation)

## Organizer

Shunkichi Isobe, NICT  
Tomoyuki Miyamoto, Tokyo Institute of Technology  
Haruo Okuda, Shonan Institute of Technology  
Hiroshi Saito, NTT (Nippon Telegraph and Telephone Corporation)  
Katsunori Sakai, Takayanagi Foundation for Electronics Science  
and Technology  
Masao Takahashi, Toshiba Corporation

## Committee Member

Michiaki Katsumoto, NICT  
Hiroshi Kikuchi, NHK  
Toshiaki Maruoka, Toshiba Corporation  
Eiju Matsumoto, The Society of Historical Metrology  
Shuichi Matsumoto, KDDI Corporation  
Takayuki Nagata, National Science Museum  
Yasuo Omori, Takayanagi Foundation for Electronics Science  
and Technology  
Yoshimitsu Ohtani, NTT  
Yoshiaki Shishikui, NHK  
Masayuki Sugawara, NHK  
Masami Sakeda, Hitachi, Ltd  
Nobuji Tetsutani, Tokyo Denki University  
Akio Toda, Mitsubishi Electric Corporation  
Yoshiyuki Yashima, NTT

© 2006

The Institute of Image Information and Television Engineers  
The Institute of Electrical Engineers of Japan