A Review of Broadcasting Technology
From Production to Distribution

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Abstract This paper presents a survey of research trends in broadcasting technology from production to distribution and from fundamentals to applications. It briefly reviews work being done on UHDTV, 3DTV, IPTV, hybrid broadcasting, transmission technology, audio-visual coding, image sensing devices, display devices, media accessibility, content production, metadata, and content management.

Key words: Broadcasting, television, production, processing, distribution, and content management

1. Introduction

Research into high-definition TV (HDTV, also known as Hi-Vision) began at the NHK Science and Technology Research Laboratories in 1964 just as color TV broadcasting had begun to get popular.

Stereoscopic three-dimensional TV (3DTV) is being broadcast these days, but more realistic forms of 3DTV, such as integral imaging, are being researched and developed with an aim of deploying it in a shorter period than it took to deploy Hi-Vision.

The spread of broadband Internet services is bringing a revolution to broadcasting technology. The Internet enables a similar functionality as broadcasting. R&D on hybrid broadcasting, which utilizes both the broadcast channel and the communication channel, is being accelerated. The spread of smartphones and tablet computers is also causing a big change in the interfaces of TV sets. That is, they will be used as not only replacements for the remote control, but also as second screens.

With that in mind, various content retrieval and recommendation techniques are being tried.

The increase in functionality and decrease in price of computers are greatly changing the systems in broadcasting stations. In the past, production and play-out systems were constructed by combining specialized equipment such as video switchers and VTRs. But today, systems consist of computers or computer-based servers, and the various functionalities are implemented in software. Computer technology has become indispensable to broadcasting.

The move towards digital equipment means that even consumer-grade equipment has enough image quality to use through the program production process. Besides bringing increased flexibility, these new technologies have caused a dramatic decrease in the price of broadcasting equipment. In addition, broadcast engineers now need to be familiar with computer technology as well as video and audio technology.

This paper is a brief survey of the trends in broadcasting technology. Although broadcasting technology may seem limited, it is not limited to the broadcasting field, as one can easily see from the history of research and development on Hi-Vision. It has had a large influence on other industries, including the audio-visual industry, film, manufacturing, surveillance, medicine, and computers. In fact, broadcasting research has led fields such as cognitive science, materials science, device development, system development, and service development. Thus, this paper is a broad survey of various technologies related to broadcasting technology.

2. Television System

2.1 UHDTV

There are two types of UHDTV - 4K (3840 × 2160
pixels) and 8K (7680 × 4320 pixels). The 4K type has four times as many pixels as Hi-Vision and has almost the same number of pixels as the digital cinema 4K format (4096 × 2160 pixels). 4K cameras and displays have already been commercialized, and digital cinema systems ranging from imaging to screening are now in use.

On the other hand, the 8K type (also known as Super Hi-Vision) has 16 times as many pixels as Hi-Vision (33 megapixels). Super Hi-Vision allows the viewer to enjoy both the sensation of presence, which is the feeling of actually being in the scene, and the sensation of reality, which is the feeling that the portrayed subject actually exists in front of them. Its format ranges from large theater displays measuring hundreds of inches to 65-inch household displays. Super Hi-Vision significantly expands the range of expressible colors; it covers more than 99.9% of the actual surface color database. Initially, devices with a frame rate of 60 Hz were developed, but today, SHV is making a transition to a 120 Hz rate that can depict smoother motion.

Super Hi-Vision conveys the audio sensation of presence and reality by using a 3D acoustic 22.2 surround system. The super multi-view display resolves the discrepancy between vergence and accommodation by projecting more than two parallactic images onto the eyes. The motion parallax of this system is limited to only the horizontal direction. A super multi-view display possessing 256 views has been developed. Moreover, it is not classified as super multi-view display in the narrow sense, a large 200-inch display using 63 HDTV projectors has been developed. It has a viewing-zone angle of up to 40 degrees and has 57 views.

### 2.2 3DTV

The 3D film “Avatar” caused a boom in stereoscopic 3DTV (S3DTV). Household TV sets equipped with S3DTV functionality are on the market, and S3DTV programs are being broadcast. Equipment and methods for producing S3DTV content are being developed, the focus being on digital cinema. Technology that converts 2D images into 3D ones, at either the production side or the reception side, has been developed to make up for the shortage of 3D content.

S3DTV exploits the phenomena of vergence and binocular disparity in the human stereo vision mechanism, and it tends to cause physiological discomfort when viewed for extended periods. In order to perceive stereo vision, humans utilize not only vergence and the binocular disparity, but also accommodation and the motion parallax. When viewing S3DTV, the focus of the viewer’s eyes is mostly on the screen surface, but in some cases, the vergence point is displaced from the screen surface in the depth direction where the stereo object is being reconstructed. This discrepancy between vergence and accommodation causes visual fatigue. In addition, S3DTV is incapable of representing motion parallax.

The research into spatial image reproduction and super multi-view displays is an attempt to make viewing 3DTV a more natural experience. Spatial image reproduction yields natural 3D images without glasses by using all the senses of human vision, i.e., binocular disparity, vergence, accommodation, and motion parallax. Holography and integral imaging are examples of spatial image reproduction. As far as holography goes, displaying a 20 fps color video with a 4 cm diagonal size within a viewing-zone angle of up to 15 degrees has been achieved with a laser beam and three 33-megapixel LCD panels. Regarding integral imaging, this method works by placing an array of microlenses in front of the camera at the time of imaging and an equivalent array in front of the projector on the display side. Its advantage over holography is that it is compatible with existing TV systems. Using a Super Hi-Vision camera and projector, a resolution close to standard-definition TV (SDTV) and a viewing-zone angle of up to 24 degrees in all directions has been achieved. To attain higher image quality, cameras and displays with resolutions greater than UHDTV will have to be developed. Recently, a method of producing integral photography images from videos captured by multi-view cameras has been developed.

The super multi-view display resolves the discrepancy between accommodation and vergence by projecting more than two parallactic images onto the eyes. The motion parallax of this system is limited to only the horizontal direction. A super multi-view display possessing 256 views has been developed. Moreover, although it is not classified as super multi-view display in the narrow sense, a large 200-inch display using 63 HDTV projectors has been developed. It has a viewing-zone angle of up to 40 degrees and has 57 views.

### 2.3 IPTV and Hybrid Broadcasting

The age when broadcasting was only over a radio wave or cable network has come to an end. Today, broadcasting can also be sent through an Internet Protocol (IP) network. Services such as Hulu in the United States and iPlayer of the British Broadcasting Corporation (BBC) provide post-broadcasting content distribution (Catch-up service) via the Internet. By utilizing Next Generation Networks (NGN), Internet Protocol Television (IPTV) provides services such as live...
broadcasting, time-shifted broadcasting, and video on demand. Adaptive streaming technology has been developed to distribute audio-visual streams, and MPEG DASH (Dynamic Adaptive Streaming over HTTP) has been standardized.

TV sets with the ability to connect to the Internet have become popular, and accessing services such as VOD via the TV set has become simple and easy. TV sets with such functionalities are referred to as connected TVs or smart TVs. The development of hybrid broadcasting systems and services, which utilize digital broadcasting and communications in a complementary fashion, is proceeding in many areas. In Europe, Germany, France, and other countries under the European Broadcasting Union (EBU) auspices have deployed Hybrid Broadcast Broadband TV (HbbTV). The United Kingdom, under the auspices of the BBC, had deployed YouView (previously known as Project Canvas). Youview service started in 2012. In Japan, standardization is ongoing based on the NHK’s Hybridcast. Such services enable viewers to access related services while viewing a broadcast program. Smart TV sets also have an environment for executing applications, and HTML5, a next-generation standard web application description language, is expected to be used as the execution environment. The W3C is discussing how HTML5 should conform to requirements of smart TVs. It is possible to use smartphones and tablet computers as remote controls and as second screens in a convenient dual-display environment. Moreover, there are new ways of enjoying TV by linking broadcasting to Social Networking Services (SNS) such as Facebook and Twitter. For instance, “JoiNTV” combines data broadcasting in digital television and Facebook. The “teleda” is an experimental SNS operated by a broadcaster, and it utilizes programs as the medium connecting viewers.

2.4 Transmission Technology
The world is in the midst of making the transition from analog to digital broadcasting. Meanwhile, advanced digital broadcasting systems with very high transmission capacities are being developed. In Europe, the digital satellite broadcasting system DVB-S2 and digital terrestrial broadcasting system DVD-T2 have been standardized and deployed. In Japan, the advanced wide-band digital satellite broadcasting system has been standardized (ARIB STD-B44). Such systems have almost twice the transmission capacity of conventional systems, thanks to their use of multilevel modulations such as 32APSK, 16APSK, and 256QAM, and error correction systems such as the Low Density Parity Check (LDPC) codes.

Systems that will vastly outperform the above-mentioned transmission systems are being researched and developed. An example of this effort is a successful outdoor experiment of transmitting compressed Super Hi-Vision signal across a distance of 4.2 km utilizing two channels of the UHF band. The use of super multi-level OFDM technology and dual-polarized MIMO enabled the experimental system to have a transmission capacity of 186.6 Mbps. Additionally, technology for transmitting uncompressed Super Hi-Vision signal over 120 GHz-band has also been developed for contribution purposes.

Aside from wireless networks, the means of performing broadband transmissions over cable and IP networks are being researched and developed. Current digital cables predominantly utilize 64QAM, but 4096QAM has been standardized in DVB-C2. It is now possible to transmit uncompressed Super Hi-Vision over optic fiber. Moreover, Super Hi-Vision has been transmitted over long distances on a global IP network.

Mobile multimedia broadcasting is currently provided in the form of One-Seg, ISDB-Tmm, DVB-H, and T-DMB. At present, research and development in this area is focusing on increasing the capacity of mobile broadcasting networks.

2.5 Audio-visual Coding Technology
Digital broadcasting currently uses MPEG-2 or MPEG-4 AVC/H.264 coding systems. MPEG-2-based and AVC/H.264-based video codecs have been developed for Super Hi-Vision. Furthermore, High Efficiency Video Coding (HEVC), an even more efficient coding system, is being standardized by the ISO/IEC and the ITU-T; It is planned to be an international standard in April 2013.

New coding schemes that maintain image quality even when the transmission capacity is limited are being researched. Research has started on coding systems that select the optimum coding method so that the system can use the optimal video format for the bitrate and improve the resolution on the receiver side by using super resolution technology. Research into distributed source coding based on the Wyner-Ziv theorem is also flourishing, and many methods that improve efficiency by utilizing side information have been proposed. Furthermore, an evolutive method that
utilizes genetic programming has been proposed\textsuperscript{77}.

3. Imaging and Display Technologies

3.1 Image Sensing

There is a continuing demand for image sensors with ever higher capabilities. The pixel size of small CMOS image sensors continues to be decreased and the pixel density continues to be increased. For instance, between 2000 and 2011, the pixel pitch has decreased from approximately 5 μm to 1.1 μm\textsuperscript{58(59)} To compensate for the decrease in sensitivity that comes with smaller pixels, many back-side illuminated CMOS (BSI-CMOS) image sensors have been developed\textsuperscript{60(61)(62)}. BSI-CMOS image sensors do not suffer from loss of incident light in the wiring layer, and their light-use efficiency is 5-10\% higher than conventional CMOS image sensors\textsuperscript{58}. It is likely that BSI-CMOS will replace CMOS image sensors.

CMOS image sensors that integrate an on-chip analog to digital converter (ADC), such as a single slope ADC or a pipelined cyclic ADC in the column parallel signal processing circuit, have been developed, and output data rates of over 30 Gbps have been achieved with them\textsuperscript{11(63)(64)(65)}. In particular, a Super Hi-Vision CMOS sensor\textsuperscript{21(65)} was developed and equipped with a pipelined cyclic ADC and a 98 parallel low voltage differential signaling (LVDS) interface. This sensor can image 33 megapixel video with a 12-bit depth at 120 fps.

CMOS image sensors composed of a 3D stack of photo detectors and circuits promise to have dramatically higher performance. Here, the aperture ratio can be increased to 100\% by placing the transistors on separate substrates, instead of together with the photo diode (PD) inside the pixels\textsuperscript{66}. Trials continue of stacked organic photoconductors for photo detectors\textsuperscript{87(68)(69)}. A high-speed CMOS imaging sensor that outputs the video signal in a direction perpendicular to the substrate has been proposed\textsuperscript{70}.

It is possible to integrate various signal processing circuits and pixel structures in a CMOS image sensor. Smart sensors with a compression or a recognition functionality\textsuperscript{71} and time of flight (ToF) based range sensors\textsuperscript{72} have been developed.

Computational photography is another approach to image sensing. It combines the ideas of image sensing and image processing. For example, high dynamic range imaging (HDRI), which composites multiple images captured under different exposures into a single image, achieves a dynamic range comparable to film\textsuperscript{73}. Image stabilization technology is used to composite subsequent images by estimating camera shake.

3.2 Displays

The use of displays as human-computer interfaces continues to grow. Various displays, including liquid crystal displays (LCDs), plasma display panels (PDPs), and organic light-emitting diode (OLED) displays have been developed.

An 85-inch Super Hi-Vision LCD has been developed\textsuperscript{4}. It has a pixel size of 0.245 mm, luminance of 300 cd/m\textsuperscript{2}, and a 1/4 multiplexing high-speed drive. New liquid crystal materials have been developed, in particular, blue phase materials which are fast and do not require orientation processing. Polymer-stabilized blue phase (PSBP)\textsuperscript{75} materials and the frequency characteristics of such materials\textsuperscript{70} have been reported.

A 145-inch Super Hi-Vision PDP has been developed\textsuperscript{77}. It has a pixel pitch of 0.417 mm, as well as a new drive system for stable panel driving.

There is a need for bigger and more power-efficient OLEDs. In particular, a 55-inch HTDV-class OLED display has been developed\textsuperscript{70}. OLED using red and green phosphorescence and blue fluorescence have superior viewing angle characteristics. The energy efficiency of these devices can be improved by inserting a color conversion layer into the R and G pixels of an RGB triplet\textsuperscript{79}. This method consumes 20\% less energy than one using color filters. As for the driving elements, oxide semiconductors are almost at a practical stage. A 13.5 inch 4k × 2k OLED display that uses IGZO in the TFT channel has been announced\textsuperscript{80}. But further research is required for mass production of oxide TFT for large-sized OLED display\textsuperscript{81}.

Research into next-generation displays includes electrophoretic E-paper capable of displaying color images\textsuperscript{82(83)} TFTs\textsuperscript{84} and OLEDs\textsuperscript{85} with superior flexibility and low-temperature manufacturing technologies have been reported\textsuperscript{86}. In addition, a diffractive optical device that increases the viewing-zone angle of stereoscopic displays has been developed\textsuperscript{87}.

The resolution of displays has been increasing as SDTV shifts to HDTV. But there is still a great deal of SDTV content, for example, DVDs. To improve image quality of low-resolution video content, display systems are or will be equipped with super resolution technology\textsuperscript{88}. 


4. Media Accessibility

Audiovisual media conveys both images and audio, and it leaves quite a deep impression on people. However, this is not always so for the hearing- or visually impaired. It can be quite difficult for persons who can only see or hear content to understand it fully. It is necessary to provide accessibility to all individuals.

Two reports to review the present status of media accessibility were published. Various trials have been performed on systems meant to improve accessibility. For example, the European project, DTV4ALL, which ran from 2008 through 2011, had the goal of improving accessibility of digital television. To help the hearing-impaired, closed captioning using automatic speech recognition is deployed. A tool to evaluate the accuracy of English subtitles has been introduced. There has been research on automatic generation of sign language computer graphics (CG)-animations. To those who were born deaf or lost hearing at an early age, sign language is even more useful than subtitles. However, sign language translation is as hard as ordinary machine translation, since spoken language and sign language have different linguistic structures. To help the visually impaired, a technology has been developed that conveys the data broadcasting in the digital broadcasting via tactile and audio means. Audio descriptions that explain the content of video verbally are provided in some TV programs, and systems to support the creation of such audio descriptions have been developed.

Background music usually does not bother adults but elderly people sometimes find it hard to follow conversations when there is music playing in the background. To deal with this problem, a technology has been developed that suppresses only the background music. Moreover, elderly people often have problems following fast conversations, and there is a technology being used that modifies the speech rate such that it can be understood easily without modifying the actual length of the entire conversation. In order to make TV audio level more human-friendly, loudness guidelines have been established. Loudness meters, which show the current loudness value, are being used in production.

Some broadcasters have multi-language services aimed at assisting foreigners in understanding broadcasts. This sort of service cannot be extended to all programming and all languages though. Trials are underway on translating the Japanese of news programs into easy-to-understand Japanese as a way of assisting language learners.

Although it has become possible to retrieve and access content through PCs and smart TVs, the usability of these devices by elderly people or children with poor computer skills should be improved. Automatic content recommendation is being studied as a way of doing so; it estimate the intentions of the viewers by analyzing their superficial behavior.

5. Content Production and Management

5.1 Advanced Content Production

Pattern recognition technology and computer graphics technology are commonly used in TV program production. Many such applications are described in a special issue of the ITE Journal. For example, in baseball programs, pitches are detected and tracked by using image recognition, and the path of the ball is overlayed on the live video in real-time by CG. In soccer programs, players’ positions are detected by using image recognition, and the off-side line is overlayed in real-time by CG. In gymnastics programs, gymnasts were captured from 12 Hi-Vision cameras and their movements are displayed from multiple angles. There is also a system to make persons who are outside studio appear to be on stage as avatars. The system uses TVML (TV program Making Language) player, a script-based CG-animation tool.

Audio production has benefited from the advent of high-quality speech synthesis of arbitrary text by utilizing a database of announcer recordings. This system is being used in radio program productions of stock market reports and weather reports.

There is a millimeter-wave mobile camera being used in various productions. It has low latency and high image quality. It operates in the 42-GHz band and uses dual-polarized MIMO. A mobile relay system capable of stable reception in the microwave band has also been developed.

5.2 Metadata Production

Metadata are important for making efficient use of audio-visual content. Since broadcasting stations operate broadcast management systems, metadata, such as the title and summary, are attached to all programs. However, the majority of programs do not have scene-level segment metadata attached to them, since it is too costly. To reduce costs, a system that attaches segment metadata during the TV program production process was developed. Attaching segment metadata is nor-
nally a laborious process, and it is difficult to attach it to live programs, for example. This technology uses content analysis to attach metadata automatically, and it is being actively researched and developed\(^\text{120}\). To evaluate the analysis technology and its feasibility in broadcasting, the EBU has set up the Media Information Management/Study of Content Analysis-based Automatic Information Extraction in Production project (MIM/SCAIE)\(^\text{121}\). Radiotelevisione Italiana (RAI) is experimentally utilizing content analysis such as shot segmentation, speech recognition, and genre classification\(^\text{122}\). However, metadata must be of high quality, and that means automatically attached metadata has to be edited manually. Integrated metadata management systems, such as the Metadata Production Framework (MPF)\(^\text{123}\), have been developed to ensure the quality of metadata. MPEG-7 has added Audio Visual Description Profiles (AVDP) which is tuned for TV programs and based on metadata models defined by the MPF\(^\text{124}\). Reference software compliant with AVDP is available from the MPF website\(^\text{122}\). The EU’s Task-Oriented Search and Content Annotation for Media Production project (TOSCA-MP)\(^\text{125}\), running from 2011 through 2014, is developing metadata attachment tools and content retrieval tools aimed at professional broadcasting.

5.3 Workflow Innovation

Although TV program production is shifting from VTR-based systems to file-based ones\(^\text{126-129}\) on computers, servers, and networks, the configuration of such productions has not significantly changed. That is set to change, however. In particular, the FIMS (Framework for interoperable media service) taskforce\(^\text{130}\) is promoting a methodology of connecting universal systems, as opposed to configuring specialized systems, via networks. FIMS is an expansion of the service oriented architecture (SOA) to program production systems. The evolution of file-based systems will continue beyond the FIMS methodology.

5.4 DRM and Authentication

Content is now being distributed over a variety of paths. Digital rights management (DRM) is a system that prevents illegal viewing and distribution of content. Since content is encrypted so it cannot be viewed illegally, DRM must have a functionality for distributing the license information that acts as a decryption key for legal users. The B-CAS system\(^\text{131}\) used in Japanese digital broadcasting defines legitimate users by distributing a smart card which contains a decryption key to individual receivers. The B-CAS system is also used for copy control. The Copy Control Information (CCI) is sent together with the broadcast content for Digital Transmission Content Protection (DTCP) and High-bandwidth Digital Content Protection (HDCP) in digital TV sets and Content Scramble System (CSS) and Advanced Access Content System (AACS) for recording media. Watermarking\(^\text{132}\) helps to prevent copying by embedding information into the video itself in an imperceptible way. For watermarking to be effective, it needs to be robust to image processing and compression. Methods that can detect and prevent illegal reshooting of screens are also being developed\(^\text{133}\).

Content distributed in an open environment such as the Internet has to be protected by countermeasures to prevent users from impersonation, tampering and wire-tapping. Digital broadcast receivers with the ability to connect to the Internet can realize a safe communication environment by distributing a root certificate over the broadcast wave, and using the Secure Socket Layer (SSL) for communication. Distributing a certificate over the broadcast wave allows digital receivers to prevent impersonator from receiving service. User authentication is important in VOD services and peer-to-peer distribution. The Public Key Infrastructure (PKI) and Pretty Good Privacy (PGP)\(^\text{134}\) are often used for these purposes. Since authentication has to be performed for each individual service, systems such as single sign on are being developed, to improve user convenience. Identity management systems such as OpenID\(^\text{135}\) and Security Assertion Markup Language (SAML)\(^\text{136}\) can perform user authentication for multiple services. Currently, the Kantara Initiative\(^\text{137}\) is working to achieve a smooth and collaborative realization of these technologies. Collaborative authentication to receive public services connected to broadcasting has been proposed\(^\text{138}\). For smart TVs equipped with application execution environments, authentication systems have been proposed to guarantee the safety of applications themselves\(^\text{139}\).

6. Conclusion

We briefly surveyed research related to broadcasting, ranging from production to distribution, to fundamentals and applications. As can be seen from the past example of Hi-Vision, R&D on broadcast technology is not limited to the field of broadcasting, but has uses in many other industries. We expect that broadcasting will be the core of a new technological revolution.
Acknowledgements

We would like to thank Dr. Masayuki Sugawara, Dr. Jun Arai, Mr. Kinji Matsumura, Dr. Yasuhiro Ito, Dr. Shinichi Sakaida, Mr. Kei Hagiwara, Dr. Takayuki Ito, Dr. Masanori Sanou, Ms. Arisa Fujii and Dr. Kazuto Ogawa for their useful information and helpful comments.

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