R&D Spirits

Toward Digital Cinema with the World's Highest Image Quality

Tetsuro Fujii
Project Manager
First Promotion Project
NTT Network Innovation Laboratories

One form of content especially suitable for the optical-fiber-network era is digital cinema. NTT Network Innovation Laboratories has developed equipment for distributing and projecting digital video with the world's highest image quality as a result of its research on super high definition (SHD) images. This innovative equipment is expected to bring about an evolutionary jump in Hollywood movies and the field of cinema in general. What kind of changes will this new system called "4K digital cinema" bring to the movie industry and information-communication services? What problems must be solved to make digital cinema a commercial success? We put these questions to Project Manager Tetsuro Fujii, the driving force behind this development project.

Development of a 4K digital cinema system praised by Hollywood

—Dr. Fujii, could you tell us something about your project's research theme?

We are working on distributing and projecting systems for super high definition (SHD) images as part of our research on encoding (**Fig. 1**). We began this research around 1990 with the aim of developing applications suitable for the optical-fiber-network era. What do we mean by super high definition? Well, high-definition television (HDTV) has 1000 scanning lines but our system has 2000. And while standard television displays 30 frames per second, our system can display 60 frames per second (**Fig. 2**). So we have doubled existing picture quality both spatially and temporally. Up until recently, we were busy developing static-image systems for the medical-treatment and engineering-design fields, but we have since shifted to moving-picture research to exploit the unique characteristics of the new world of optical fiber networks with its high bit rates. Our main target is digital cinema [1], which we call "4K" for approximately 4000 pixels horizontally. Picture quality in movies is expressed by the number of pixels in the horizontal direction. Thus, HDTV, which has 1920 pixels horizontally, is called a "2K" system. While existing versions of digital cinema are mostly based on the HDTV 2K level, our 4K system corresponds to the world's highest level of image

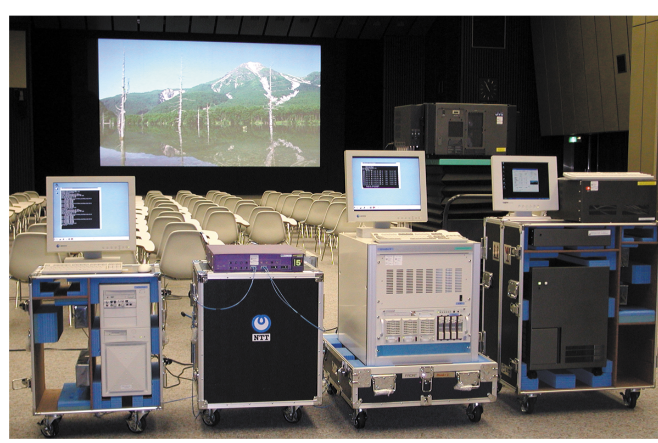

Fig. 1. SHD digital cinema distribution system.
From the left: PC-server, GbE-hub, JPEG2Krealtime decoder and projector (GbE: gigabit Ethernet).

quality in digital cinema. Furthermore, equipment such as ours cannot be found anywhere else. This level of quality is appreciated by even Hollywood and is being incorporated into digital cinema standards. We are working to commercialize digital cinema using NTT's optical fiber network in cooperation with people from the Hollywood movie industry.

—What is the main technical issue surrounding this research?

That would be the search for a coding system oriented to picture quality. For the remote medical-treatment system that we worked on prior to digital cinema, it was important to ensure accuracy for diagnostic purposes, and this created a great need for reversible image coding. For that reason, we especially focused on lossless coding. Similarly, for motion pictures, we set out to develop a system paying particular attention to how we could deliver a picture having the highest possible quality in each frame. In this regard, JPEG and MPEG can display only 8 bits of data for each of the RGB (red/green/blue) components, which does not really provide enough depth of color for movies. To improve upon this, we developed equipment that could run JPEG2000 and display 10 bits per color.

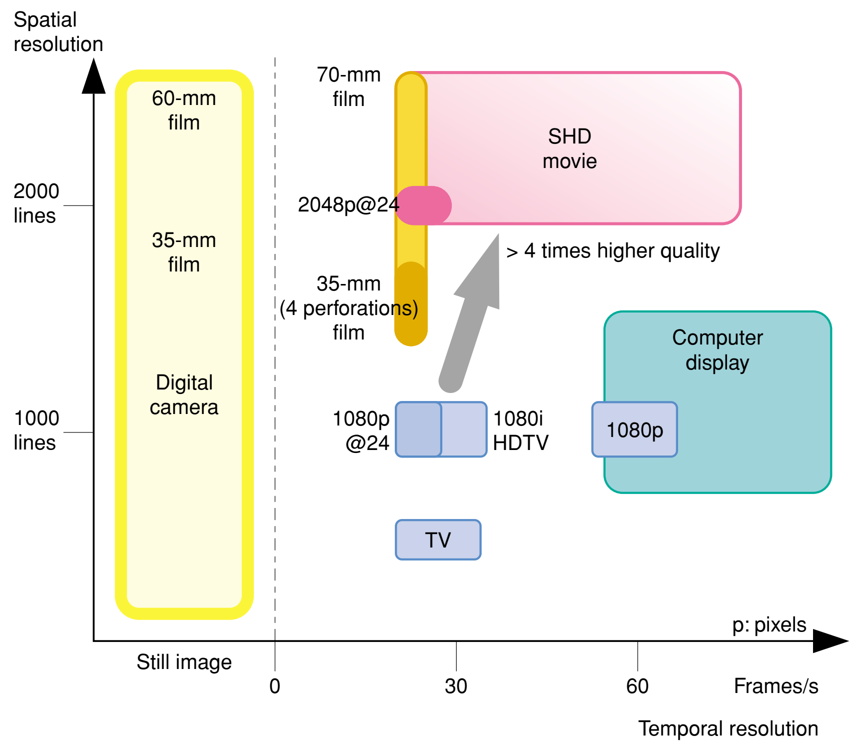

Fig. 2. Characteristics of SHD digital cinema.

—Were there any breakthroughs in this development?

Yes. There have actually been two breakthroughs. The first was the recognition that we received from a Hollywood engineer when we demonstrated our system at the 2001 SIGGRAPH exhibition in Los Angeles. At that time, there was much concern about next-generation cinema. Everybody wanted higher quality movies, but there was no equipment to provide them. Some people thought that HDTV was the way to go, and much debate on this ensued. It was against this background that engineers associated with the movie industry in Hollywood came to SIGGRAPH to check out new trends in motion-picture technology. I'll never forget the emotion I felt when one of those engineers observed our video images and exclaimed "This is exactly what we want!" It was at that time that we began researching ways of adapting our equipment to digital cinema.

The second breakthrough occurred during a demonstration that we gave in 2002 at the Entertainment Technology Center of the University of Southern California. This demonstration was attended by a wide range of movie-industry people including representatives from the seven major Hollywood studios, members of the American Society of Cinematographers, and the chief technical officer of the Digital Cinema Initiatives (DCI), an organization devoted to drafting global standards for digital cinema. All of these people came to evaluate our digital cinema system, and it was here that they decided to adopt our system as "4K digital cinema." A proposal for a global standard on image quality in digital cinema was later drafted at DCI in accordance with our ideas.

—What is your specific business plan here?

We can think of two formats in which we could develop business for digital cinema. The first is the distribution of digital cinema by file transfer in which content that is currently being delivered by physical distribution would be provided to users via optical fiber. The technology for this type of distribution is nearly complete. What remains to be done is to extend optical fiber to movie theaters and introduce projectors for digital cinema, which is expected to occur in the not-too-distant future.

The second format is the distribution of digital cinema by streaming. The development of digital cinema facilities will make it possible to present sports events, concerts, musicals, and other forms of entertainment in real time. This format will be the second phase of business development following completion of the first format that I just described. In this second phase, we will target not only movie theaters but also municipal halls and other venues to expand the market for digital cinema. For this format, however, there are still a number of technical issues that must be addressed, and we expect phase two of our business strategy to take longer (**Fig. 3**).

—*What problems are you faced with at present?*

One problem is the development of security technology for digital cinema. Needless to say, a major worry of people in the movie industry is movie piracy. In the case of analog film, the process of supplying such movies to movie theaters is such that the copying and videotaping of films is not rare. Digital film, on the other hand, can be encrypted and digitally watermarked, for example, enabling security for movies to be maintained and managed in ways not possible with analog. Hollywood has high expectations in this regard. We are currently working on the development of digital watermarking techniques for digital cinema in collaboration with the NTT Cyber Communications Laboratory Group.

We also need to find an appropriate transmission system for achieving realtime streaming of digital cinema. Here, as well, development work is underway. Achievements to date include 300-Mbit/s streaming of digital cinema from Chicago to Los Angeles, and 400-Mbit/s streaming from a server in Keihanna Research Park (in western Japan) to a hall in Tokyo during a symposium held during last fall's Tokyo International Film Festival. The latter experiment amazed even visitors from the Hollywood movie industry. They hinted that such a successful streaming experiment for digital cinema could only be done in Japan. For the projection of Japanese movie called "Shitsurakuen," at this Tokyo International Film Festival, our group received the 2004 AMD Award for Digital Contents of the Year—Technology Prize.

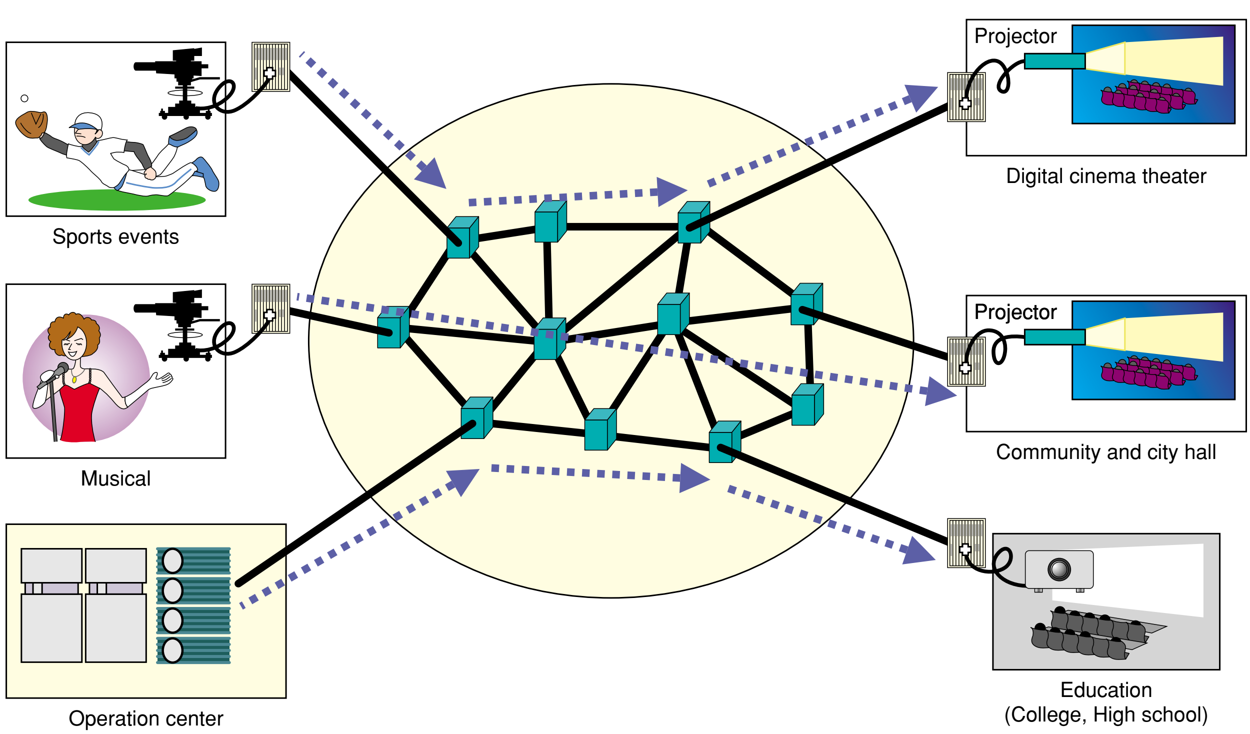

Fig. 3. Optical networks for high-quality images.

—How do you think this research will evolve in the years to come?

In our minds, the main point is not simply the spread of 4K digital cinema but rather its connection to distribution services by optical fiber networks. Delivering content by physical-distribution means, as has been done in U.S. digital-cinema trials, would not constitute a successful experiment as far as we are concerned. The content would absolutely have to be delivered by an optical fiber network. Moreover, in the next phase, we are aiming at the streaming of digital cinema as I described earlier. I see digital cinema as a process that once begun cannot be stopped, and in this sense, I would like to see it expand into a system that can deliver live content throughout Japan via streaming.

Taking the lead in digital cinema by adopting international standards on 4K systems

—Dr. Fujii, what is happening in the world of digital cinema elsewhere in the world?

Well, to begin with, various types of equipment are being constructed to present digital cinema at the 2K level. In Japan, there are currently 20 or so screens for digital cinema, but these are all 2K-HDTV systems manufactured in the United States. At the same time, Japan has been strong in the digital-imaging and digital-video fields from the start, and the cameras, projectors, and displays now being used in Hollywood are mostly Japanese made. It is therefore no surprise that Japan is out in front in 4K technology, and various Japanese companies including NTT have each been trying to be the first to market a 4K system.

Consequently, on seeing the results of Japanese R&D and current Hollywood trends in digital cinema, you would think that the market for 4K systems is very promising. Even the defense industry in the United States is beginning to make inroads into this market. Nevertheless, there is still some hesitation to invest in 4K systems. Optical fiber networks in the United States have yet to be fully deployed, and to make matters worse, antitrust laws dictate that movies studios and movie theaters cannot invest capital in each other, which results in less than desirable management of movie theaters on the whole. In short, an environment for achieving digital cinema has not really been established. The situation there is different from that in Japan where the optical fiber network is nearly complete and where movie theaters, production companies, and distribution companies have cross-capitalization relationships, making investment in digital cinema relatively easy. For this reason, the way we look at digital cinema is somewhat different how they look at it in the United States.

As for Europe, digital cinema is seen as a potential and important form of entertainment during the winter months especially in northern Europe, and there is a strong desire to achieve digital cinema as soon as possible. There is also much enthusiasm for standardization in Europe, but if anything, priority is being placed on early deployment as opposed to the technology itself. But some countries, like the U.K. and Italy, treat movies as an industry, and they feel that technology is also important in deploying digital cinema in the right way. The approach to digital cinema therefore differs from region to region.

—How are standardization efforts coming along?

There are basically two global organizations that are now studying technology for displaying high-quality movies on large screens. The first is the Society of Motion Picture and Television Engineers (SMPTE). This organization is typical of those promoting movie and video standards, but in terms of movies, their activities are especially focused on the Hollywood movie industry. You might remember the DCI proposal that I mentioned earlier. Actual standardization based on this proposal is to be finalized by a SMPTE committee called DC28. In this regard, it is our intention to develop equipment conforming to SMPTE standards as early as possible and to become a market leader in digital cinema.

The other organization is the International Telecommunication Union Radio Communication Sector (ITU-R), which deals with issues related to broadcasting. Whereas standardization at SMPTE is focused on digital cinema for movie theaters, the talk at ITU-R is about standardization of large screen digital imagery (LSDI). The idea here is that enjoying TV on large screens much as you do at a theater is a natural extension of TV’s historic growth to date. Content here would include movies (other than newly released films) and live broadcasts such as ones of sports events and concerts. This trend is especially strong in Italy, France, and the U.K. LSDI standards do not stand in opposition to SMPTE standards but are being prepared using them as a base.

—What role does NTT play in these standardization activities?

First of all, there is only one set of equipment making up a complete 4K system in the world, and that is the equipment on our site. Under these circumstances, we cannot help but agree to requests for demonstrations and the like. We have already established a partnership with DCI and we are offering technical advice to ITU-R. We have also initiated discussions with the European Digital Cinema Forum (EDCF) on the spread and use of 4K systems.

Achieving original results: the thrill of research

—Dr. Fujii, how did your R&D career begin?

In my fourth year at university, I analyzed brain waves, and as part of my research on adaptive filters during my master's and doctoral courses, I worked on algorithms for adaptive-equalizers and echo cancellers. Signal processing was therefore my starting point as a researcher, and it has become a core technology for me.

—Could you tell us something about the research that you have been involved with up to now?

Well, for about one year after entering NTT, I researched echo cancellers as an extension of my university studies. I actually presented a well-organized paper about the analysis of algorithms for stereo echo cancellers at that time. This research, though, was ahead of its time, and the results presented in that paper did not attract much attention on release. Just the other day, however, I was talking with a researcher from an electrical equipment manufacturer, and he said that my paper has since become the "bible" in this area. Next, in my second year at NTT during a time of organizational restructuring, my research shifted from audio to video though remaining in the field of signal processing. I began to investigate how digital signal processors (DSPs) for video applications should be designed, and during that time, I constructed a parallel processing system called NOVI, achieving a level of performance that was then the world's highest for such systems. But around the same time, optical fiber and asynchronous transfer mode (ATM) were becoming practical, and I began to realize that image-related applications were more appropriate for optical networks than metallic ones. It was at this time, around 1990, that I entered the world of super high definition images.

From the very start of this research, the group that I was in chose moving pictures as its main target. But as our research progressed, we also came across applications based on still pictures. We therefore decided to start our search for a practical application of SHD images using still pictures, and we began in the field of medical treatment. In 2000, as a joint-research project with the Keio University School of Medicine, we completed an SHD X-ray viewing station using a 28-inch, full-color, liquid-crystal screen incorporating all of the devices and functions needed for remote diagnosis conferencing. This system also attracted the attention of the art world, and in 1997, it was used for a presentation at the Whitney Museum of American Art in New York City. At present, there are efforts in Japan to build archive systems using our 4K system as a platform. Our system has also been incorporated into CAD/CAM processes in the automobile industry, and it appears that many units of such equipment are being used. In this way, we first worked on achieving working systems using still images, but at the same time, research on our original target of moving pictures advanced steadily bringing us to our present research activities.

—Is there anything in particular that you came to pursue during the course of all this research?

Yes. One thing would be signal processing technology. I don't mind saying that I can hold my own with anyone when it comes to signal processing. Another thing would be 4K digital cinema. When I began research on SHD images, my superiors and colleagues would say "one day, we'll all be seeing movies in SHD." At that time, it was no more than a dream, but today, after 15 years, a realistic system is within reach, and while completion may still lie some years ahead, this is still a very emotional time for me.

—What do you find interesting about research work?

I enjoy the challenge of trying to do something that no one else has done. Thinking up an entirely new method or achieving results that no one else in the world has obtained can be a deeply moving experience. I was fortunately able to experience this feeling early on with my university graduation paper. In actuality, no one knows how useful the fruits of research will be to society. Nevertheless, the thrill of research can be experienced quite early in a researcher's career. Once you have felt that thrill, you are driven to seek it again. Even if you have felt it many times before, it is still a fresh and invigorating feeling of joy when it hits again. If a researcher should ever lose this sense of excitement, he might do better to take up another line of work.

A desire to explore new worlds with signal processing technology at the core

—Dr. Fujii, what are your future aspirations?

There is much talk by the people around me that our next challenge will be an 8K system. I myself don't have much interest in tackling 8K right now. Of course, 8K and even 16K are conceivable from a strictly numerical viewpoint. But, in reality, I don't see a feasible business vision for 8K or higher systems even if reasons can be found for exploring the technology for them. This is because the maximum size of film in use today is 65 mm, and this can be sufficiently supported by a 4K system. In other words, as there are no business requirement of 8K and 16K levels of quality, it would be way too early to enter that field now. Accordingly, I could see myself taking on a completely different research theme only when everything that needs to be done for 4K has been satisfactorily dealt with. Though I do not have any specific ideas at this time, I believe that there are still many things that I could pursue based on signal processing technology, my specialty.

—What is your ultimate dream as a researcher?

I would love to be able to enjoy SHD video, the current target of my research, in my own home. If digital cinema can be achieved in the theater, it is natural to expect the next step to be digital cinema in the home. At present, there is still no strategy for expanding the distribution of 4K movies to the home, but just the same, I would like to make it possible to see my favorite content with a beautiful picture whenever I like while resting comfortably on a sofa in my home.

—What is it like working at NTT Laboratories?

Whenever I am outside in the real world, I feel as if my wish has been granted. Signal processing technology, which lies at the core of my work, has provided me with a basis not only for creating algorithms but also for producing systems that are useful for society. NTT Laboratories has provided me with a very enjoyable and gratifying work environment.

—Dr. Fujii, could you leave us with a message for young researchers?

I'd be happy to. It is important that you find your core technology as a researcher as early as possible. Without such a core, it is going to be difficult to decide on your approach to research. Even if you come to be involved with various research themes, and even if you can discuss particular topics with other researchers, having a core technology is going to make a world of difference. One of my jobs as a manager is to help young researchers find their core technology, but the truth is that a researcher will never develop a core without making a personal effort. To become a good researcher, I believe you have to find your core technology early on and make an effort to embrace it.

Reference

[1] T. Yamaguchi, D. Shirai, T. Fujii, and T. Fujii, "SHD Digital Cinema Distribution over a Global High-speed Network: Internet2," NTT Technical Review, Vol. 1, No. 5, pp.10-15, 2003.

Interviewee profile

■ Career highlights

Tetsuro Fujii received the B.E., M.E., and Ph.D. degrees in electrical engineering, from the University of Tokyo, Tokyo, Japan in 1979, 1981, and 1984 respectively. In 1984, he joined Nippon Telegraph and Telephone Public Corporation (now NTT), Japan. He stayed at the University of California, Berkeley, from 1988 to 1989, as a visiting researcher. He has been engaged in research on adaptive signal processing, image signal processing, and transport processing. His current interest is super high definition image processing and its application to digital cinema. He became a Project Manager of First Promotion Project, NTT Network Innovation Laboratories in 2004.

■ Major awards

Achievement Award of IEICE (The Institute of Electronics, Information and Communication Engineers) in 2004. Best Technical Achievement Award of AMD (Association of Media in Digital), 2005.