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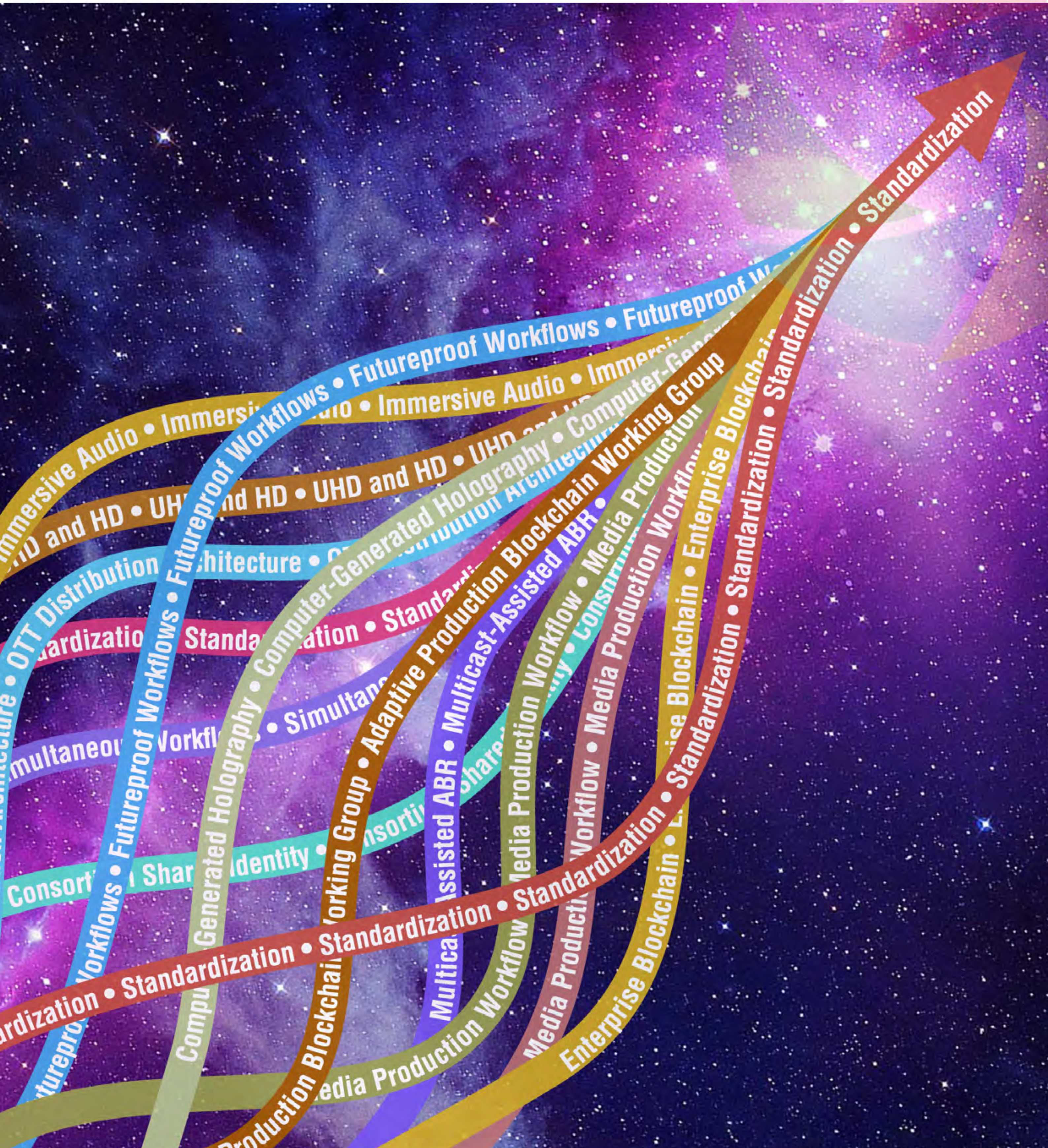

Live Production System to Handle Video Signals With Various Aspect Ratios

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Introdução:

Você já se perguntou como os broadcasters fazem para harmonizar diferentes conteúdos que possuem diferentes *Aspect Ratios*? Eu também! Exatamente sobre isso que o artigo desta edição trata. Aqui os autores investigam os requisitos do sistema e métodos de transmissão específicos tanto para transmissão ao vivo, quanto de pós-produção nas emissoras. Propondo inclusive a possibilidade de gerenciamento de sinais de vídeo com vários números de pixels e *aspects ratios* diferentes (16:9/2.4:1/1:1) na produção ao vivo. Eles consideraram, não apenas a flexibilidade de produção usando vários formatos de vídeo convencionais (SD, HD), mas também escalabilidade para gerenciar vídeos em UHD. Borá matar esta curiosidade e aprender como se faz!

Tom Jones Moreira

Abstract

To provide an aspect-free television (TV) service that allows viewers to watch more attractive TV programs using various aspect ratios based on the creator's intent, we investigate the system requirements and specific transmission methods for live production in broadcast stations. We propose the use of a 16:9 active video area in conventional video signals such as high-definition (HD)/ultrahigh-definition-1 (UHD-1) as containers and determine the range that the user-specified aspect ratio video occupies in the container using identifier ancillary data. This method is highly compatible with existing systems and conventional workflows. Scalability using multiple containers is considered in this study.

Keywords

Aspect ratio, compatibility, container, identifier, live production, scalability

Introduction

Aspect ratio is the video parameter that represents the numerical ratio between the width and height of a picture. In television (TV) broadcasting, 4:3 was used for standard-definition (SD) TV systems. Subsequently, 16:9, which was calculated from the film aspect ratio of 2.35:1 and the SDTV system aspect ratio of 4:3 by using the shoot-and-protect technique,[1] has been used for the high-definition (HD) TV system. Since the launch of HDTV, and through ultrahigh-definition-1 (UHD-1) and UHD-2 video formats, the aspect ratio for broadcasting has been fixed at 16:9.

Although producers in broadcast stations can only use a fixed aspect ratio of 16:9, various aspect ratios are also used in other video production industries. In filmmaking, depending on the producer's intent, the aspect ratio used for shooting can be set to values such as 2.35:1 or 2.4:1 for "scope" size, or 1.85:1 for "flat" size, in addition to 16:9. In recent years, based on video media services, in general, with the expansion of over-the-top (OTT) video content distribution and distribution from broadcast stations via the internet, the number of video production cases with various aspect ratios and video content has increased. In OTT video services, video formats different from those currently being broadcast are used, that is, HD or UHD-1 with 16:9, for example, the use of 1:1 and vertical aspect ratios, which are mainly used in video services for social network services such as Instagram Live.[2] Specific to vertical video services is increasing the number of video service formats that are mainly transmitted to devices and viewing formats that are different from those of conventional TV.

Although producers in broadcast stations can only use a fixed aspect ratio of 16:9, various aspect ratios are also used in other video production industries. In filmmaking, depending on the producer's intent, the aspect ratio used for shooting can be set to values such as 2.35:1 or 2.4:1 for "scope" size, or 1.85:1 for "flat" size, in addition to 16:9. In recent years, based on video media services, in general, with the expansion of over-the-top (OTT) video content distribution and distribution from broadcast stations via the internet, the number of video production cases with various aspect ratios and video content has increased.

In such new trends, some cases are arising where broadcasters produce content using non-16:9 aspect ratios. TV content that involves aspect ratios other than 16:9 is increasing, such as TV dramas or commercials that use wide aspect ratios. For example, to accommodate OTT viewing styles, live video of a soccer game of Bundesliga, a German soccer league, was produced in a 9:16 vertical aspect ratio for live-streaming distribution.[3] In this trial, the conventional video interface for 16:9 was used, and production equipment such as cameras and displays were operated in a bespoke manner and rotated by 90°. Hence, in a broadcast video production environment, where baseband signals designed for 16:9 are managed, significant equipment barriers exist for shooting in other aspect ratios. Furthermore, the video production can be operated using the desired aspect ratio of 9:16 in a bespoke manner; however, if the producer wishes to use other special aspect ratios, then the video production cannot be managed operationally; instead, a specific equipment is required for each aspect ratio.

To add more information regarding interfaces issues, although SMPTE ST 2110,[4] a new standard for an interface between studio equipment, specifies that the use of videos with various numbers of pixels is allowed, the current commercial equipment only allows the selection of certain typical video formats. This includes the conventional aspect ratio of 16:9, which is used in HD and UHD-1, and suggests that even video equipment with the ST 2110 standard is inadequate in terms of broader aspect ratio requests.

Regarding the current home viewing environment and styles for video contents with various aspect ratios, letterbox or pillarbox viewing is typically conducted. Furthermore, the resolution is scaled such that the content can be displayed inside the 16:9 aspect ratio of the display. However, this may not provide a satisfactory viewing experience and may not be achieved depending on the difference in aspect ratios between the content and the display. However, in the current OTT service, even when the aspect ratio is changed, the preferred viewing experience is maintained by changing the window shape in the application so that no black bars appear in the window. The cutting-edge display trends suggest that video walls as well as form-free or foldable display devices[5] are being marketed. In the future, as shape-changing displays that behave in the same way as OTT window changes become a norm, more expressive and attractive TV programs using various aspect ratios will be transmitted equally to both broadcasting and internet platforms.

To develop a new system that allows the management of video signals with various aspect ratios at broadcast stations, we investigated the system requirements and specific transmission methods for live production. Because video production with various aspect ratios has been achieved in nonlive production environments such as nonlinear editing systems, which are also being used in movies and OTT videos, we assume that the video production environment for broadcast stations, the subject of our research, is live production in a studio that manages baseband signals designed for the 16:9 aspect ratio.

An important consideration in our study is to allow the management of video signals with various aspect ratios in live production and transmission at broadcast stations by only slightly changing the current system (thereby incurring a low cost) and adhering to a conventional workflow. We assumed that two platforms exist for video services (broadcasting and internet infrastructure) and that aspect ratio switching is operated per program in the current video service. In addition, the program production at each studio was done in a single preselected aspect ratio video format. Furthermore, we considered not only flexibility for production with various conventional video formats, but also scalability for managing video formats beyond UHD-2, as recommended in International Telecommunication Union-Radiocomunication (ITU-R) Recommendation BT.2123.[6] In the system investigated, the video format is not limited to the range of conventional formats; instead, new standard video formats that will emerge in the future are applicable, and migration to future services are considered.

In this article, we begin with an introduction to an aspect-free TV production system and an overview of the services that use it. Next, we discuss the system requirements for managing video signals of various pixel numbers and aspect ratios and present implementation examples.

Aspect-Free TV Production System

We considered providing an aspect-free TV production system and service that uses it, which allows producers to select various pixel numbers and aspect ratios based on their intent for the program, and viewers to shape the aspect ratio of the display device to match the aspect ratio used for each program. To realize this service, we describe the future vision of the in-broadcast system and the manner by which services will be provided, as well as provide a comparison between the conventional and future production studios. **Figure 1** shows an overview of the in-broadcast system and signal flow from a production studio, focusing on the master control room to the platforms. Studio A is a conventional production studio that supports only 16:9. When outputting 16:9 from Studio A, the signal is processed conventionally, regardless of whether it is a broadcasting platform or internet platform. If a video program with a non-16:9 aspect ratio is output, then the program will be packed into a 16:9 canvas using video editors or processors, managed as packed 16:9 video signals and then transmitted to the broadcasting platform via the master control room. The output to the internet platform and the archives may still be delivered as a packed 16:9 video, which is currently the process for TV.

By contrast, Studio B is a future-type production studio, where the number of pixels and the aspect ratio used for production can be adjusted based on user request. The signal transmission within the broadcast station uses the same interface as that of 16:9, regardless of the differences in the aspect ratios. When outputting from Studio B using an aspect ratio other than 16:9, such as 2.4:1 or 1:1, and using nontransformable home displays in the interim, the letterboxed video is sent out to broadcasting platforms, and the original 2.4:1 video is sent out to or retained in the internet platform and archives. In the future, after transformable futuristic TV displays have been adopted in homes, the output for broadcasting

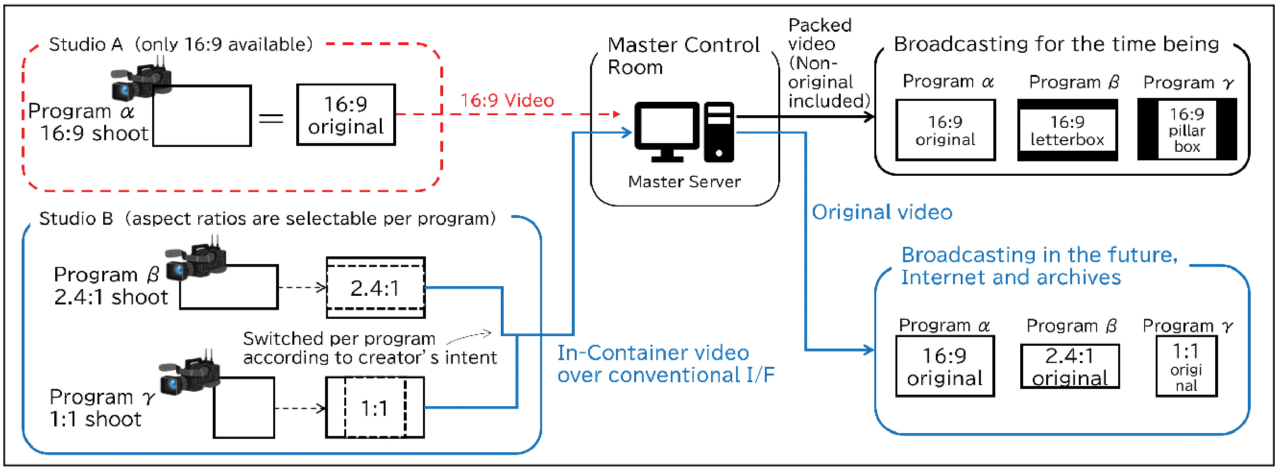

FIGURE 1. Overview and signal flows of an in-broadcast system.

platforms will be the original 2:4 or 1:1 video as well as the output to internet platforms and archives.

Design Considerations

This section describes the considerations for designing an in-broadcast system for live production and transmission that supports various aspect ratios, which are necessary for realizing the system described in the previous section. To realize a system that allows producers to freely set a number of pixels and aspect ratios, as described in the earlier section, we argue that video production companies should minimize the effect of introducing the system. The upcoming section provides the conditions that are constraints for minimizing the introduction effect. The following section describes a strategy for realizing the system under the constraints presented in the section below.

Constraints Arising from Consideration of Lower Implementation Effect

- **Compatibility With Conventional Interfaces in Broadcast Systems**

Interface replacement involved in a new installation incurs additional equipment and financial cost overhead, for example, the necessity for numerous converters during the transitional period of system migration.

- **Transmission Rate and System Clock**

It is desirable to use a fixed transmission rate and system clock because changing them for the entire system based on the individual video format settings of each user incurs significant time costs for implementation and debugging in individual devices.

- **Maximum Number of Transmissible Pixels**

By considering the compatibility of interfaces, the maximum number of transmissible pixels is constrained by the number of pixels specified by the conventional interface.

Strategy for Designing System Under Constraints

First, considering the interface compatibility, SDI or IP, which is typically used in the current production and transmission facilities, is used as the interface in the proposed system. Next, to allow users to freely set the number of pixels and aspect ratios even when the transmission rate and system clock are fixed, a conventional fixed active video area, that is, HD, UHD-1, and UHD-2 with frame sizes of 16:9, should be used as a container for storing video frames with any number of pixels and aspect ratio to be set by the users. The container method is used considering the following: the synchronization signal can be shared with existing 16:9 video signals, the synchronization of video per frame can be performed easily because of the timing match, and the mutual exchange of signals with existing systems is simple. To identify the active video area, which refers to the number of pixels and the aspect ratio set by the user in the container, identifiers synchronized with each frame are embedded in the interface. When the conventional 16:9 video service is used, compatibility is ensured by omitting the identifier.

In addition, the system should be expanded to allow multilink transmission such that it can be expanded to a number of pixels that exceed the size of each container unit: HD, UHD-1, and UHD-2. Finally, in terms of equipment utilization efficiency, the same equipment can be used to produce different numbers of pixels and aspect ratios by switching the settings.

Requirements

The following underlines the five system requirements to fulfill the strategy described in the previous section.

Requirement A: Identification of Container Formats

The interface between the production equipment in each studio and between the production studio and the master control room uses the same SDI and IP baseband signals as those used previously. The number of pixels and the aspect ratio of the video signal to be transmitted are those used in the current broadcast station, that is, HD, UHD-1, and UHD-2 with an aspect ratio of 16:9, and one frame of each 16:9 format should be used as a container. To identify the video format to be used as a container, the existing payload ID defined in SMPTE ST 352 can be used.[7] Therefore, data addition is not required to indicate the video format of the container, except the addition of the payload ID.

Requirement B: Identification of Container Number and Mapping Structure

The total number of connected links of the physical interface for container transmission (i.e., the total number of containers), the container number, and an identifier indicating the mapping structure of the video with multiple containers must be determined.

- **Total Number of Containers and Container Number**

The identification signals to manage the total number of containers and container numbers are reserved as ancillary data in a separate area from the payload ID. For example, when quad-link 3G-SDI[8] is used as a container unit to transmit UHD-1 video data, the assignment number of quad-link is specified in the payload ID. Therefore, to avoid conflicts, the identification signals that manage them must not be specified.

- **Mapping Structure**

As a mapping structure for videos with multiple containers, the array structure between multiple containers and the mapping structure of subimages to be stored in each container must be confirmed, for example, 2-sample interleaving (2SI) and square division (SQD) in quad-link SDI transmission. For the mapping structure of multiple container transmissions, two types of methods corresponding to 2SI and SQD in quad-link SDI are adopted to simplify the implementation. However, unlike quad-link SDI, the total number of containers is not necessarily four in either case, depending on the degree of freedom in the order of containers in the array structure described below. In other words, it does not correspond to the 2 × 2 subimage structure of conventional 2SI and SQD and is therefore not exactly the same as 2SI and SQD, however, for convenience, we use the terms 2SI and SQD.

- **Array Structure**

The array structure should be designed to support not only the conventional horizontal aspect ratio, but also the 1:1 and vertical aspect ratios. This implies that, for example, in a transmission involving four containers using HD (1920 × 1080) containers, the area allocated by the four containers can be defined not only as 3840 × 2160 (two rows and two columns), but also as 1920 × 4320 (four rows and one column).

- **Links on Which Ancillary Data Are Embedded**

The identifiers described above are embedded in each video signal supporting each container such that even when any video signal supporting a container is received independently, the entire video area reserved by all of the containers and the partial area of the entire video area encompassed by the container can be confirmed without the ancillary data of other containers.

Requirement C: Identification of Active Video Area

An identifier indicating the range of the active video area to be used is multiplexed in the ancillary area. In the case of transmission by multiple containers, these identifiers are embedded in each container for the same reason as described in the explanation for requirement B.

Requirement D: Inheritance and Sharing Range of Identifiers

Within the production studio, the identifiers described are embedded in the output signal of at least each video resource such that it can be verified as to whether the individual video resource is in the specified video format to be used. In addition, between the studio and the master control room, the signal transmission device from the production studio to the master control room retains the identifiers used in the studio such that the number of pixels and the aspect ratio can be identified and switched in the master control room.

Requirement E: Support for Multiple Formats and Equipment Control

In terms of equipment utilization efficiency, the same equipment can be used to yield different numbers of pixels and aspect ratios by switching the settings. To support multiple aspect ratio switching, the equipment in future production studios should allow the identifier to be changed to satisfy the user-specified aspect ratio. The production studio video equipment control system is centralized, and the aspect ratio switching of each device is collectively controlled by an external application.

Implementation

Based on the requirements described in the earlier section, we provide the signaling details for managing video signals of various numbers of pixels and aspect ratios. Implementation in interfaces is explained—two examples with specific video formats are provided to illustrate the implementation of the proposal.

Production Studio Overview

This section provides an overview of the production studio that will be constructed based on the requirements outlined in the previous section. **Figure 2** depicts an overview and signal flows within a future-type production studio, such as Studio B, as illustrated in **Fig. 1**. Prior to program production, the equipment and video formats used for the program were registered in the system management application. Based on the instructions, identifiers for specifying the active video area used in the container were defined and communicated to each video resource, video processor, and multimonitor in realtime by the resource provider. Based on the identifier, a multimonitor was used to change the layout, thereby ensuring convenience.

Case 1: 2560 × 1080 (2.4:1) Supported by Two HD Containers

For Case 1, **Fig. 3** illustrates an example of transmitting a video signal with a total pixel count of 2560 × 1080, aspect ratio of 2.4:1, frame frequency of 30 Hz progressive, and YCbCr 10-bit using two HD containers. SQD was used for the container array. A UHD-1 camera was used as the video resource. As the interface for the camera output, 3G-SDI (level B-DS)[9] was used.

First, the camera uses a portion of the UHD-1 (3840 × 2160) image sensor area to capture the desired 2560 × 1080 area. The left half of the active area was assigned to container No. 1 and the right half to container No. 2. The number of pixels in each active area was 1280 × 1080. Each container contained images captured by the UHD-1 image sensor that did not correspond to the active area. However, because this area was not subject to processing in the later steps of the system, the captured images can be output without modification, or can be filled with a specific pattern such as a black mask to allow the user to easily understand the active area in the container. Because each container comprises 1920 × 1080 pixels and a frame frequency of 30 Hz progressive, it can be output via two interfaces as a dual-link HD-SDI signal. However, for simplicity of cable management, we provide an example of outputting a 3G-SDI level B-DS multiplexed in two HD-SDI signals supporting two containers.

The identification signals in each container are listed in **Table 1.** ID 1 indicates the total number of containers used for transmission, which is 2 for both the No. 1 and 2 containers. ID 2 shows the array relationship formed by all the containers. ID 3 indicates the identification number of each container, that is, 1 for container No. 1, and 2 for container No. 2. The counting order of the containers in ID 3 is as follows: the top-left container is No. 1, and it is counted to the right; when the counting of containers in the same line is completed,

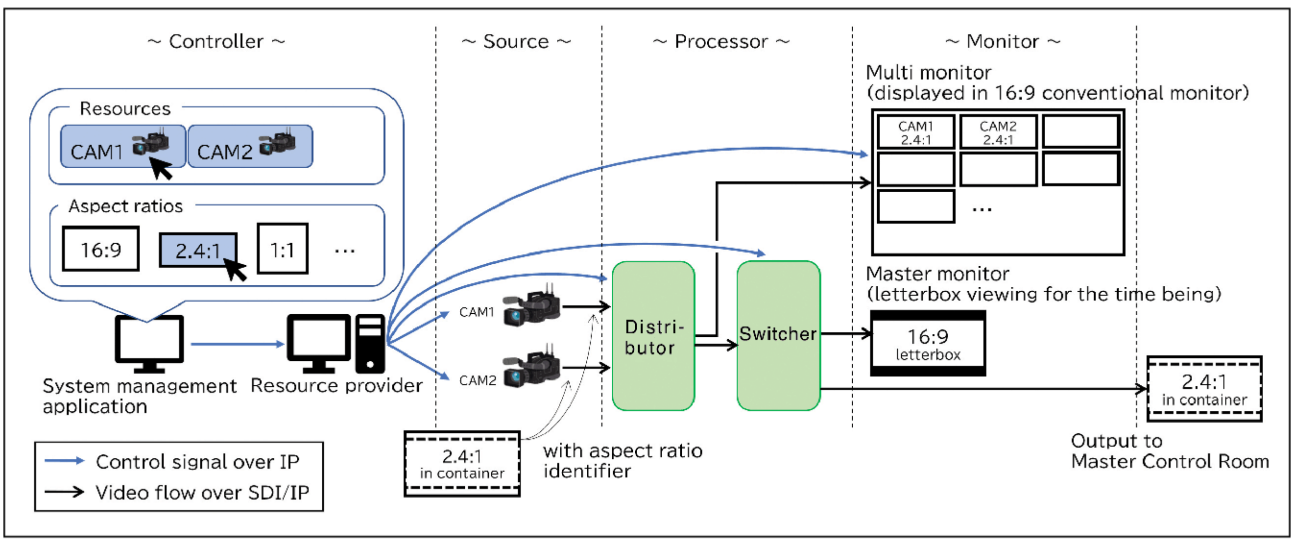

FIGURE 2. Overview and signal flows in a production studio.

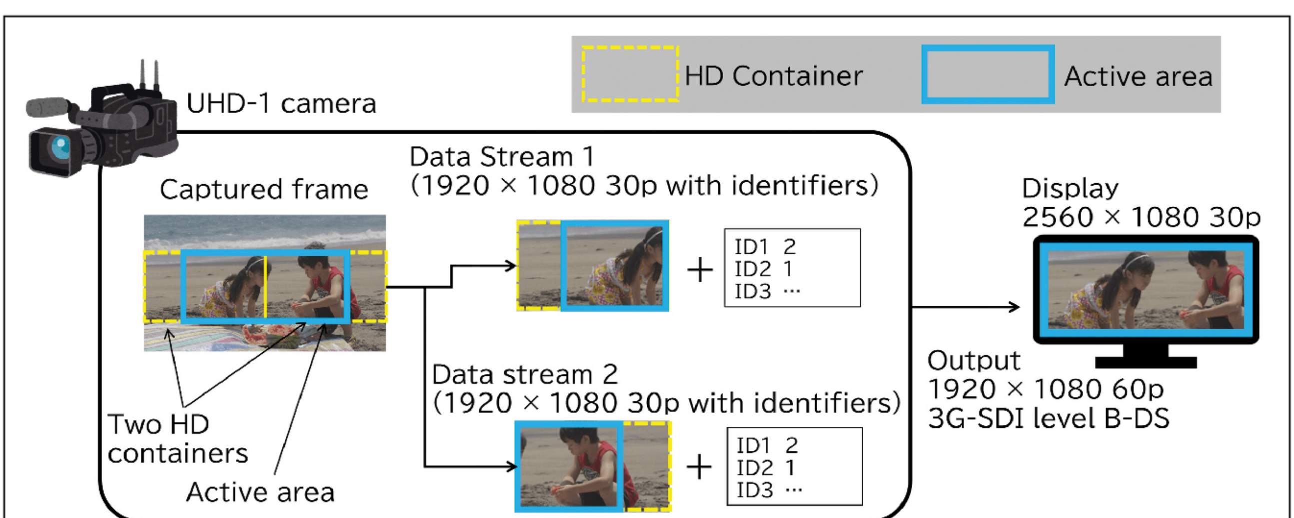

FIGURE 3. Signal flows in Case 1, 2560 × 1080 (2.4:1) supported by two HD containers.

TABLE 1. Identification signals in Case 1, 2560 × 1080 (2.4:1) supported by two HD containers.

ID No.	Parameters		Container No. No. 1	Container No. No. 2
ID 1	Total number of containers		2	2
ID 2	Array	Rows	1	1
		Columns	2	2
ID 3	Container No.		1	2
ID 4	Mapping structure		Square Division	Square Division
ID 5	Total container size	Horizontal	1920	1920
		Vertical	1080	1080
ID 6	Active area size	Horizontal	1280	1280
		Vertical	1080	1080
ID 7	Offset	Horizontal	320	–320
		Vertical	0	0

the container one line down is recounted from the next number to the right. ID 4 indicates the video mapping structure within multiple containers, where either 2SI or SQD was selected. In this example, the SQD was used to ease discussion. ID 5 indicates the total number of pixels in the video format used as the container, for both the horizontal and vertical directions. The active video area shown as ID 6 and the offset shown as ID 7 are data that indicate the location of the active area in the container. Several formats can be used to indicate the location of the active area; however, in this study, we used the format described in SMPTE ST 2016-2[10] as well as four parameters: the number of pixels in the horizontal and vertical directions, and the number of pixels offset from the screen center to the horizontal and vertical directions.

Case 2: 30,720 × 15,360 (2:1) Supported by 16 UHD-2 Containers

For Case 2, **Fig. 4** illustrates an example where a video signal is transmitted with a total pixel count of 30,720 × 15,360, an aspect ratio of 2:1, frame frequency of 60 Hz progressive, and YCbCr 10-bit, as specified in ITU-R BT.2123,[5] using 16 UHD-2 containers. The interface for transmitting each container was quad-link 12G-SDI,[11] and SQD was used for the 16-container array, as in Case 1. Unlike Case 1, the description of the transmitting and receiving equipment is omitted for simplicity, and only the containers are described.

First, an effective video area measuring 30,720 × 15,360 was obtained using a portion of the area of the 16 UHD-2 (7680 × 4320) container arranged in a 4 × 4 arrangement, that is, 30,720 × 17,280 pixels. Here, the position of the active area in all containers that were aligned with the top of the container was used as the active area. For the horizontal direction, because the number of pixels matched the number of horizontal pixels of the aligned container, no offset was required.

The identification signals contained in two typical containers are listed in **Table 2.** Because the values of other identifiers were the same for all the containers numbered from 1 to 12 and from 13 to 16, except for ID 3, which is the identification number of each container, containers No. 1 and No. 13 are described herein. ID 1 indicates the total number of containers used for transmission, that is, 16, which applies to container Nos. 1 and 13. ID 2 indicates the array relationship formed by all the containers. Sixteen containers were arranged in a 4 × 4 matrix, that is, four rows and four columns, which applies to container Nos. 1 and 13. ID 3 indicates the identification number of each container, that is, 1 for container No. 1 and 13 for container No. 13. ID 4 indicates the video mapping structure within multiple containers, where either 2SI or SQD was selected. In this example, as in Case 1, SQD was used for ease of discussion. ID 5 indicates the total number of pixels in the video formats used as the containers. In this example, for container Nos. 1–12, the total number of pixels in the container and the number of pixels in the active area were the same. In contrast, for container Nos. 13–16, the active video area size (vertical) was 1,920, which represents the number of pixels different from the height of the container, and the offset (vertical) was 1,200, which is a nonzero value because a portion of the upper area of each container was used. The offset (vertical) was a nonzero value of 1,200.

Discussion

Based on the implementation example described, we discuss the following three aspects: the selection of mapping structure, avoidance of vendor lock-in in program exchange, and future prospects.

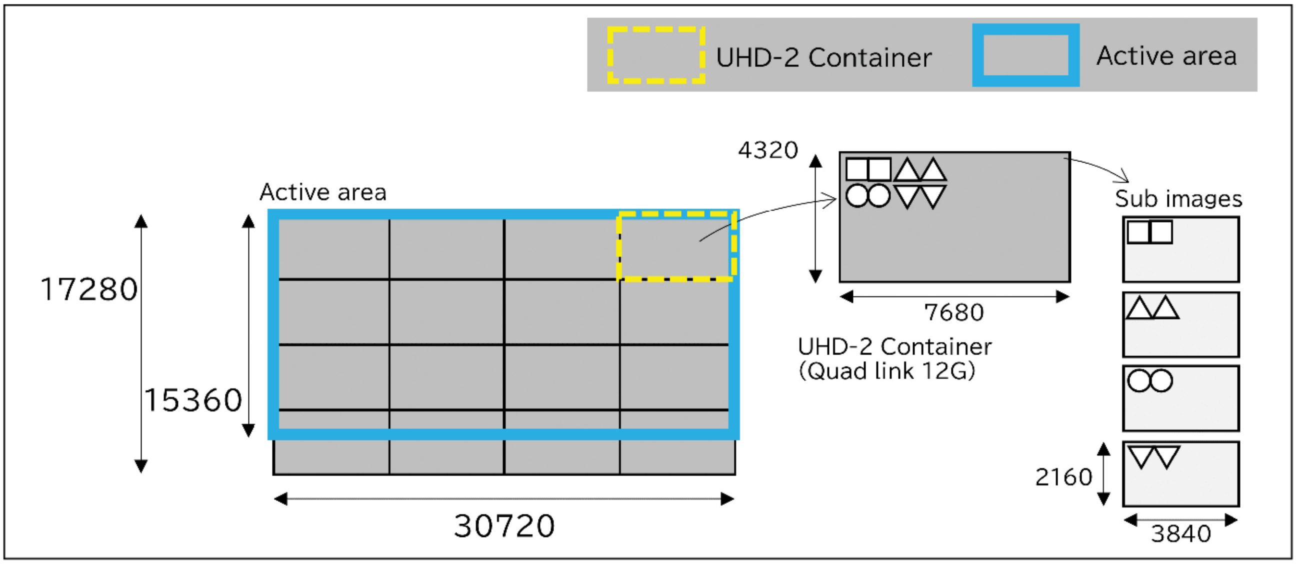

FIGURE 4. Relationship between active area and containers in Case 2, 30,720 × 15,360 (2:1) supported by 16 UHD-2 containers.

TABLE 2. Identification signals in Case 2, 30,720 × 15,360 (2:1) supported by 16 UHD-2 containers.

ID No.	Parameters		Container No. No. 1	Container No. No. 13
ID 1	Total number of containers		16	16
ID 2	Array	Rows	4	4
		Columns	4	4
ID 3	Container No.		1	13
ID 4	Mapping structure		Square Division	Square Division
ID 5	Total container size	Horizontal	7680	7680
		Vertical	4320	4320
ID 6	Active area size	Horizontal	7680	7680
		Vertical	4320	2400
ID 7	Offset	Horizontal	0	0
		Vertical	0	–960

Selection of Mapping Structures for 2SI and SQD

The selection between 2SI and SQD in the mapping structure is considered based on the implementation issues. For example, SQD requires a considerable amount of internal memory to draw the transmitted video frame compared with that required for 2SI, and the system delay required to draw the frame is significant. This issue occurs during multilink transmission in the proposed system, particularly when many pixels are transmitted, as in Case 2. As most of the products in the current market are operated with 2SI, which is advantageous in terms of memory and system delay, it is preferable to store the mapping structure of the subimages in containers because the active area is based on 2SI in the multilink transmission for the proposed system.

Necessity for Standardization

Several solutions are available to realize the realtime composition and baseband output of videos with an arbitrary number of pixels and aspect ratios. However, most of them are not suitable for program exchange or general-purpose interconnected operations of devices, which are typically performed between studios in broadcast stations, because the interfaces used between devices and the management and detection methods of active areas differ among manufacturers. To avoid such vendor lock-in and conduct program exchange without relying on particular equipment, a solution is to devise a common method that can transmit an arbitrary number of pixels and aspect ratios, as shown herein, as well as exchange the accompanying identifiers among diverse equipment. In other words, the transmission method and the identifier description method should be standardized. In addition, in cases where a program is recorded and delivered for secondary use or program exchange as material, guidelines for pass-through, recording, and retention of identifiers for specifying the active video area in video equipment in the production studio will also be necessary to ensure that the identifiers are properly retained.

■ **Future Prospects**

We regard the proposed system as a transitional one until a future production system based on IP and software becomes a norm. As mentioned in the previous section, the ST 2110 standard allows the use of videos with various numbers of pixels and aspect ratios. Therefore, if the requirements and orientation for video production using various formats increase, new devices that support the transmission of individual formats within the scope of the existing ST 2110 standard should be developed and commercialized. In recent years, file- and software-based production systems and workflows have flourished. For example, among the file formats, the interoperable master format, defined as the SMPTE standard,[12] is designed based on this orientation, which retains the entire angle of view of the shot and specifies a portion of it with ancillary data, such as the number of pixels and aspect ratios, based on the platform to be sent out. Furthermore, files can be managed based on a concept similar to the relationship between the containers and active areas described herein. When in-broadcast video production workflows using software represented by cloud services become a norm, the ability to freely set video parameters for input and output videos is likely to be expected.

Conclusion

To provide an aspect-free TV production system and service that use it, we investigated the system requirements and specific transmission methods for live production in broadcast stations. An important consideration in our study was to enable the management of video signals of various numbers of pixels and aspect ratios in live production and transmission at broadcast stations by implementing only slight changes to the current system and adhering to a conventional workflow. Furthermore, we considered not only production flexibility using various conventional video formats, but also scalability for managing videos beyond UHD-2.

Considering the constraints to minimize the introduction effect, we presented five requirements for an in-broadcast system to be used for live production and transmission to support various numbers of pixels and aspect ratios, as well as an overview of the system concepts. As a solution, we proposed a multiple container transmission method that is compatible with the current equipment and adheres to the conventional workflow using conventional interfaces with additional identifiers to manage the total number of containers and active video area sizes. In future studies, we would like to consider standardization while considering the trends of broadcasters, other content providers, and manufacturers.

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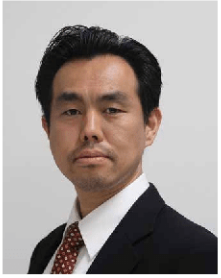
He joined NHK in 2008 after receiving a BE in electrical engineering and an ME degree in computer science and engineering from Waseda University, Tokyo, in 2006 and 2008, respectively. He has been engaged in the research of UHDTV camera systems since 2012. He is a member of ITE.

Kosuke Nomura received BE and ME degrees in electrical engineering from Tokyo University of Science, Tokyo, Japan, in 2010 and 2012, respectively. He joined NHK in 2012. Since 2016, he has been working for NHK STRL and in charge of the research from HDR to SDR dynamic range conversion and psychological impression evaluation regarding various aspect ratio video. He is a member of ITE.

Kenichiro Masaoka is a principal research engineer at NHK STRL. He received a PhD in engineering from the Tokyo Institute of Technology, Tokyo. He worked with Prof. Mark Fairchild and Prof. Roy Berns for a six-month residency as a visiting scientist at the Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY, in 2012. He is a member of SMPTE. Currently, he is the chair of the Color Metrology Subcommittee and the Spatial Measurements Subcommittee of the International Committee for Display Metrology. He was named a Fellow of the Society for Information Display in 2021.

Yuichi Kusakabe is a senior research engineer at NHK STRL. He is engaged in the research of video system, displays, and coding system for ultrahigh definition television. He has been working on standardization of video system such as HDR in International Telecommunications Union–Radiocommunication (ITU-R) SG6 and the Association of Radio Industries and Businesses (ARIB).



Satoshi Oode joined NHK in 1999, and received a PhD degree in information sciences from Tohoku University, Sendai, Japan, in 2019. He is involved in standardization of audio matters including 22.2 multichannel audio and object-based audio and actively participates in International Telecommunication Union–Radiocommunication (ITU-R) WP6B and WP6C, SMPTE, European Broadcasting Union (EBU), and ARIB. He was associated with the work that resulted in the ITU-R specifications for advanced sound systems, including loudspeaker configurations, loudness measurement algorithm, subjective evaluation methods, audio-related metadata (the audio definition model—ADM), its serial representation, audio digital interface, and 64-bit audio file format (BW64). He is currently the vice chair of the ITU-R WP6C and the chair of the ITU-R subworking group 6C-1 Audio, which is developing an advanced sound system and the ADM renderer.

Takayuki Yamashita is currently working on the research, development, and standardization of television systems including UHD/HDR as a senior research engineer at NHK STRL. He codeveloped the world's first 8K camera system in 2002 and signal interface for UHDTV system in 2013. He joined NHK in 1995 and has been engaged in research on camera systems for broadcasting since 1999. He received the BE and ME degrees from the Kyoto Institute of Technology, Kyoto, Japan, in 1993 and 1995, respectively, and a Dr.Eng. degree from Ehime University, Matsuyama, Japan, in 2016. He is a member of SMPTE and ITE.