RECOMMENDATION ITU-R BT.1201*

Extremely high resolution imagery

(Question ITU-R 226/11)

(1995)

The ITU Radiocommunication Assembly,

considering

a)   that extremely high resolution imagery could be used as future imaging systems in various fields, such as computer graphics, printing, medical, motion pictures, television and so on;

b)   that for constructing such systems, it is necessary to consult with many experts in various related fields on images;

c)   that studies and application experiments on extremely high resolution imagery are being conducted in various parts of the world;

d)   that common usage of devices is preferable for economical implementation of the extremely high resolution imagery systems;

e)   that bit-rate reduction technologies take a major role in transmission of the extremely high resolution imagery;

f)   that required spatial and temporal resolutions and aspect ratios may differ depending on the applications in the market place;

g)   that conversion of spatial and temporal sampling lattices are becoming possible between different formats without introducing artifacts to the converted images,

recommends

1   that spatial and temporal resolution and picture aspect ratio should be flexible enough to meet a variety of requirements in different application fields. Annex 1 gives examples of current development work;

2   that a header in the data stream should be used to define the parameters specified in § 1 above;

3   that commonality of colorimetry should be achieved in different formats.

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*   Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

ANNEX 1

Progress report on extremely high resolution imagery (HRI)

1 Introduction

Because of the physical limitations in technologies which are available in the real world, most of the applications described in this Recommendation are in non-real-time areas. To investigate realization issues in § 3 a model has to be assumed. Because of the reasons listed above, in spatial resolution hierarchy, the following conventions are used in this Recommendation.

A hierarchy of spatial resolution models are assumed in § 2 as indicated in Table 1.

TABLE 1

A hierarchy of spatial resolution models

	HRI-0	HRI-1	HRI-2	HRI-3
Spatial resolution (number of samples)	1 920 × 1 080	3 840 × 2 160	5 760 × 3 240	7 680 × 4 320

The hierarchy is based on 16:9 screen aspect ratio but this is just for sake of discussion.

HRI-0 to 3 are simple multiples of integers in horizontal and vertical directions.

The HRI hierarchy is defined spatially and on the temporal axis the image is assumed to be stationary (or in non-real time). In the real-time case it is classified by specifying the frame rate.

2 Current situation

2.1 Still and picture-by-picture image processing (currently in practice)

It is reported that in recently released films digital film-optical effects are intensively used and this makes the films very attractive to the majority of audiences. The digital film-optical effects, i.e., electronic processing on film, set a new stage for film making, efficiently replacing the previous film optical processes by the cost-effective and well-established studio post-production techniques. These are compositing with computer-generated graphics, film matting and compositing by blue-screen keyer, retouching of scenes to remove unwanted landscapes and colour and gradation changes for old and decayed films. There are several such systems available in the market and they are successfully used. To compose the whole system, a CCD film scanner, an output film recorder and a signal processing facility are used. Workstations and relevant software packages are usually used to realize these effects. The equipment can handle film quality of extremely high resolutions; that is more than 40 times of conventional TV signal resolutions.

2.2 Computer graphics (CG)

Images for graphics arts can be generated by computer graphics. The images are generated by off-line, and there are no serious technological problems involved. If the disk capacity used is large enough and a high-speed computer is used, parameters such as spatial resolution, screen aspect ratio, temporal resolution and others, can be set, in principle according to the demands. However, creation of moving images on a real-time basis is difficult to realize with current technology. It depends on the complexity of the image to be produced and the CG technology used. Image generation by simple CG technology, makes some applications, such as virtual reality systems, flight simulators and game machines, possible in real-time.

For current HDTV programme production, approximately one hour is required using a 200 MIPS computer to generate one frame of a human image. If an HRI-3 level of image is to be produced with the same technology, 16 hours will be needed to generate a 4×4 times higher resolution image. Availability of huge CPU power in terms of MIPS and an adoption of dedicated graphics engines are always the key for generating high resolution images in CG.

In present graphic workstations, the most common display parameters are 4:3 screen aspect ratio, square pixels, 60 frames progressive scanning, $1\,280 \times 1\,024$ pixels, and a total 32 bits gradation in colour and in grey scale. In recent models, $1\,600 \times 1\,024$ pixels and a total 48 bits gradation are adopted.

3 Realization issues

3.1 Display technology

3.1.1 CRT (cathode ray tube)

In CRT displays with an image size of about 20 in, a resolution of about 1000 lines can be achieved at a shadow mask pitch of about 0.3 mm. In high-level workstations, a 0.15 mm pitch has already been realized. The mask pitch depends on many technical factors, like the thickness of the mask and manufacturing conditions. With the present technology level the limit is estimated to be about 0.16 mm in the 40 in size of CRT. Current spot size of the electron beam is around 1-2 mm. To have higher resolution it is necessary to reduce the size of the spot to around 0.5-1 mm.

It is also necessary to increase the driving speed of CRT deflection circuitry. This is achieved by reducing the width of the deflection yoke wire and by lowering the loss at the core. To reduce deflection errors a digital compensation circuit will be necessary.

3.1.2 LCD (liquid crystal display)

There are two alternative applications of LCD technology to the display of high resolution imagery. For direct-view type LCD the availability of a larger size liquid crystal panel will be a potentially large problem in terms of technology and cost involved. For high resolution image display, a larger size screen is always requested by viewers. In this regard, projection type LCD has a problem of tradeoff between expensive optical systems for a larger size liquid crystal panel and the lower brightness gained from a small size liquid crystal panel.

3.2   Acquisition technology

3.2.1   TV camera

The marginal resolution of a lens system for practical use is assumed to be about 100 lines/mm. Therefore, the achievable vertical resolution by a 1 in lens system (CCD scanning area of 14×7.8 mm) is $7.8 \times 100 \times 2 = 1560$ TV lines, and it is considered that an optical system that is larger than 1 in would be necessary in a system above HRI-1 level ($3\,840 \times 2\,160$).

When a higher resolution is required, the pixel size of image pick-up devices tends to decrease. The low sensitivity is alleviated by such measures as enlarging the light-receiving surface, adopting a high sensitivity element, and reducing the noise level.

Regarding the number and the size of pixels, a prototype of a 2 million-pixel (2/3 in optical system) CCD has been announced as a two-dimensional CCD for television. Not the reduction of size but expanding the surface of the chip devices which can cover up to HRI-1 is considered achievable within several years. A new technology would be necessary for further increase of resolution.

The reduction of the S/N ratio of a camera lowers the compression rate. Thus, lowering the noise level is a prime importance.

3.2.2   Telecine

Three different image pick-up methods are currently adopted in telecine. Those are image pick-up tube camera or CCD image pick-up area sensor, flying spot scanner, and laser scanner. Most of the problems originating in the high resolution imagery with those techniques come in real-time telecine operations. If the applications are in non-real-time, almost all the problems disappear in its slow speed scanning operations.

3.2.3   Electronic still camera

The image quality of silver salt photography using 35 mm film is almost equivalent to that of the HRI-1 class. Handling of much higher resolution is possible by enlarging the size of the film used.

Presently, for exclusive use for still images, a 2 in $\times 2$ in CCD with 4 million pixels, which correspond to the resolution between HRI-1 and HRI-2, has been realized. Much higher resolution is to be accomplished by a new device to replace CCD.

3.3   Transmission technology

3.3.1   Optical transmission

With the use of the 1.55 μm wavelength, a transmission rate of more than 2.5 Gbit/s and a relay interval of 100 km has been realized. As the optical transmission system has a very large transmission capacity compared to other systems, it is assumed that it will be the basic transmission system in any future use of advanced digital images.

Table 2 shows several potentially important fields in development of optical transmission technology to convey the future high bit-rate signals in HRI real-time applications. It can be easily seen that some innovative break-through technologies are indispensable.

TABLE 2

Issues on technology development of optical relay transmission

	In the case where 150 Mbit/s is the applied transmission ratio for real-time HRI-0 and 1[1]	In the case where 600 Mbit/s is the applied transmission ratio for real-time HRI-2 and 3[1]
Optical relay transmission technology	Optical transmission technique up to 100 Gbit/s Coherent light wave transmission technology Light modulation technology FDM (10 waves) Light amplification technology	Optical transmission technique up to Tbit/s bit level Coherent light wave transmission technology Light modulation technology FDM (100 waves) –

[1]   See Table 9 for definitions of the real-time HRI-0 -1 -2 -3.

3.3.2   Satellite broadcasting

As for broadband satellite broadcasting, frequencies from 21.4-22 GHz (600 MHz) assigned by the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) may be used. In this case, from the viewpoint of the bandwidth in the travelling-wave tube (TWT), etc., it is possible to realize broadcasting satellite repeaters at about a 300 MHz bandwidth. However, in actual broadcasting, from the aspects of electric power generation and the scale of the satellite, attenuation and atmosphere absorption attenuation of the 21 GHz band radio wave must be overcome by changing the radiation power according to the amount of rainfall of each region. The following technical developments are necessary for this purpose:

–   highly efficient, lightweight, and high-output TWT,

–   space synthetic antenna,

–   electric power synthetic technology,

–   radiation power control technology.

3.3.3   CATV

Regarding CATV, compared with the present analogue transmission, real-time transmission of HRI signals requires the following measures:

–   the use of multichannels,

–   realization of better quality transmission,

–   higher speed and broader bands,

–   use of digital and optical technology.

Table 3 lists an example of a combination between a bandwidth and modulation levels for each member of the real-time HRI transmission hierarchy.

TABLE 3

Bandwidth and modulation levels for HRI transmission

Real-time HRI transmission hierarchy[1] (After compression)	Combination between a bandwidth and modulation levels
HRI-0 (50 Mbit/s)	12 MHz/64-QAM
HRI-0 and 1 (65-130 Mbit/s)	24-36 MHz/64-QAM 18 MHz/256-QAM
HRI-2 and 3 (500 Mbit/s)	100 MHz/256-QAM (optical fibre cable required)

[1]   See Table 9 for definition of the real-time transmission hierarchy.

3.4   Storage technology

3.4.1   VTRs

The technology trend extrapolated from home use VTRs (8 mm, VHS) shows that 1.0-2.5 bit/μm^2 by the year 2000 can be expected. Table 4 indicates available recording surface areas for each type of cassette on the market.

TABLE 4

Recording surface areas for cassette tapes

Tape	8 mm cassette	VHS cassette
Tapes in the markets (width, length, thickness)	(8 mm, 106 m, 10 μm)	(12.7 mm, 246 m, 19 μm)
Tapes to appear in 2000 (width, length, thickness)	(8 mm, 212 m, 5 μm)	(12.7 mm, 467 m, 10 μm)
Effective recording area of the tape (90% of the width used)	1.52×10^{12} μm^2	5.33×10^{12} μm^2

To record the real-time HRI signals an application of some form of compression algorithms to input recording signals is considered mandatory. Table 5 shows estimated recording capacity for each VTR format under consideration.

From Table 5, it is considered that a ratio higher than 1/60 is required for real-time HRI-3 signal recording.

The calculations below are estimates based on the assumptions made from the current surface recording trend. In order to realize a recorder for each HRI hierarchy in the real world some other considerations have to be taken into account.

TABLE 5

Estimated recording capacity of VTRs by the year 2000

Real-time HRI hierarchy[1]	Original signal bit rate (Gbit/s)	Cassette type	Moving picture (h)			Still picture (No. of sheets)
			Compression ratio			Compression ratio
			1/60	1/30	1/4	1/10
HRI-0	2.5	8 mm	8	4	0.5	3×10^5
2 million pixels		VHS	27	14	2	1×10^6
HRI-1	10	8 mm	2	1	0.1	7×10^4
8 million pixels		VHS	7	3	0.5	3×10^5
HRI-2	40	8 mm	0.5	0.2	0.03	2×10^4
19 million pixels		VHS	2	0.9	0.11	6×10^4
HRI-3	72	8 mm	0.3	0.1	0.02	1×10^4
33 million pixels		VHS	1.0	0.5	0.06	3×10^4

[1] See Table 9 for definition of the real-time hierarchy.

3.4.2 Disks

The technology trend, extrapolated from the current disk technologies, shows that 4 to 9 times of increase in recording capacity by the year 2000 can be expected. Table 6 indicates available recording capacity for each size of disk currently on the market.

TABLE 6

Recording capacity to be achieved by the year 2000

Storage media	Size (mm)	Recording capacity (Mbyte)
MD	64	600-1 350
CD-ROM	120	2 720-6 120
LD	300	18 200-41 000

To record real-time HRI signals an application of some form of compression algorithms to input recording signals is considered mandatory. Table 7 shows estimated recording capacity for each disk format under consideration.

TABLE 7

Estimated recording capacity of video disks by the year 2000

Real-time HRI hierarchy[1]	Original signal bit rate (Gbit/s)	Storage media	Moving picture (h)			Still picture (No. of sheets)
			Compression ratio			Compression ratio
			1/60	1/30	1/4	1/10
HRI-0 2 million pixels	2.5	MD CD-ROM LD	0.06 0.3 1.7	0.03 0.1 0.8	– 0.02 0.1	2×10^3 9×10^3 6×10^4
HRI-1 8 million pixels	10	MD CD-ROM LD	0.01 0.06 0.4	0.01 0.03 0.2	– – 0.03	5×10^2 2×10^3 2×10^4
HRI-2 19 million pixels	40	MD CD-ROM LD	– 0.02 0.1	– 0.01 0.05	– – 0.01	1×10^2 6×10^2 4×10^3
HRI-3 33 million pixels	72	MD CD-ROM LD	– 0.01 0.06	– – 0.03	– – –	7×10 3×10^2 2×10^3

Table 7 shows the recording capacity when technology improvement is expected to be 9 times the present level. The Table clarifies that in motion images, a compression ratio of 1/30 in HRI-1 and HRI-1 will make the recording time too short, and 1/60 will realize a recording time close to that of current analogue recorded LD.

3.5   Coding and image processing technology

Ultra-definition images of the real-time HRI signals involve enormous amounts of information. In order to maintain high image quality while effectively and economically reducing the bit rate up to the point corresponding to the characteristics of the transmission and storage media, it is essential to develop a higher efficiency algorithm and a faster signal processing technology for encoding and decoding. Based on the studies of previous coding technology carried out by ITU-T, the International Organization for Standardization (ISO)/the International Electrotechnical Commission (IEC) and other standardization organizations, the possibility of establishing a coding algorithm for real-time HRI signals is discussed in this section.

Table 8 shows the magnitude of contribution, in the total bit-rate reduction ratio achieved, by each functional technology or each element of algorithm available today.

TABLE 8

Compression efficiency of each element of the algorithm

Compression in the frequency domain: discrete cosine transform	5-10
Compression in the temporal domain: motion compensation	2-3
Compression by the statistical characteristics of data: variable length coding	1.3-1.5
Average compression ratio	15-30

Table 9 shows the compression ratio required for transmission for each real-time HRI image.

TABLE 9

Required compression ratio for transmission

Image hierarchy	H. 26X/ MPEG-2	Real-time HRI-0	Real-time HRI-1	Real-time HRI-2	Real-time HRI-3
Number of effective pixels	720×483	$1\,920 \times 1\,080$	$3\,840 \times 2\,160$	$5\,760 \times 3\,240$	$7\,680 \times 4\,320$
Sampling frequency ratio	4:2:2	4:2:2	4:2:2	4:4:4	4:4:4
Gradation (luminance colour difference) (bit)	8	10	10	12	12
Frame rate/s	30	60	60	60	60
Source signal bit rate (Gbit/s)	0.216	2.5	10	40	72
Transmission ratio (Mbit/s)	5-10	60-80	100-150	150-600	150-600
Compression ratio	20-40	30-40	70-100	70-270	120-480

The marginal value of the compression ratio at which the viewers will seldom notice image quality degradation after secondary distribution will be 15 to 30, as was indicated in Table 9. Additional reduction of the bit rates shall be possible by utilizing HVS (human visual sensitivity) characteristics or filtering. Therefore, compression up to 1/25 to 1/50 is considered possible to achieve a secondary distribution quality. However, as far as the image quality of the contribution level is concerned, a compression ratio of about 1/6 might be the limit.

In the case of top hierarchy level, it is necessary to realize a compression ratio of 300-500. For this level of compression, some form of breakthrough is required. A knowledge-based coding, which is still in the research phase, is one candidate.

Table 10 summarizes availability, in terms of time, of the fundamental devices which are required for processing of real-time HRI signals.

Items in the encoder/decoder rows of Table 10 related to single chip implementation. It may also be possible to develop multiple-chip hardware based on parallel processing schemes. This approach makes hardware implementation much easier.

TABLE 10

Relevant devices and their availability for the real-time HIR signal processing

Items for study	Real-time HRI-0	Real-time HRI-1	Real-time HRI-2	Real-time HRI-3
A/D converter	Mass production possible by around 1994 or 1995	May be possible Realization expected around 1997	Difficult under present technology Breakthrough required	Breakthrough required
D/A converter	Mass production possible	Trial production level No problem	May be possible Realization expected around 1997	May be possible Realization expected around 2000
Maximum sampling frequency required	Approximately 150 Hz	Approximately 500 Hz	Approximately 1.2 Hz	Approximately 2.0 GHz
Frame memory capacity (per frame)	Mass production possible No problem 40 Mbit	Trial production level No problem 165 bit	May be possible Realization expected around 2000 670 Mbit	May be possible Realization expected around 2003 1.2 Gbit
LSI processing and integration	Possible 0.5 μm	May be possible 0.35 μm In trial production phase	May be possible 0.25 μm Realization expected around 2000	May be possible 0.15 μm Realization expected around 2003
Encoder logic LSI (1 chip) DSP (1 chip)	6 million transistor Possible May be possible (as a special purpose VLSI chip)	12 million transistor Possible (New architecture required) Almost impossible Breakthrough required	30 million transistor Almost impossible Breakthrough required Breakthrough required	100 million transistor Breakthrough required Breakthrough required
Decoder logic LSI (1 chip) DSP (1 chip)	2 million transistor Possible May be possible (as a special purpose VLSI chip)	5 million transistor May be possible May be possible (as a special purpose VLSI chip)	12 million transistor May be possible (New architecture required) Almost impossible Breakthrough required	30 million transistor Almost impossible Breakthrough required Breakthrough required

LSI: large scale integration circuit
DSP: digital signal processor

4   Parameters

TABLE 11

A set of parameters for extremely high resolution imagery

Parameters	Values
Screen aspect ratio	4:3 and/or 16:9 are basic sizes but other values may also be adopted taking various purposes into account
Spatial resolution	Taking into consideration computer compatibility, $1\,920 \times 1\,080$ and/or its integer multiple are preferable on 16:9 screens to realize square pixels
Temporal resolution	With respect to the scanning system, a progressive scanning system must be adopted as this system shows characters and figures containing lateral stripes, and it also attains easier image coding or image processing than interlaced scanning systems. It should be noted that higher spatial resolution generally requires higher temporal resolution. A system which adopts approximately 60 frames/s and progressive scanning system is appropriate for a time
Gradation	8 bits for moving images and 10 bits for still images are essential. It may be necessary to utilize 12 bit gradation to correspond with sophisticated signal manipulations such as image compositions, video editing and secondary uses
Colorimetry	It seems the colorimetry described in Recommendation ITU-R BT.709 is appropriate for a while, but it may be necessary to utilize a new method which can realize a wider range of colour reproduction