International Telecommunication Union



Report ITU-R BT.2160-1 (10/2010)

Features of three-dimensional television video systems for broadcasting

BT Series Broadcasting service (television)



Telecommunication

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Note: *This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication Geneva, 2011

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Summary

The technology needed for a first-generation three-dimensional television (3DTV) two-channel stereoscopic system already exists, although so far there have been no announced plans for the general introduction of regular free-to-air broadcasting services. A number of broadcasting organizations nevertheless continue to carry out experiments in stereoscopic 3DTV production, while pay-television operator BSkyB has announced its intention to introduce a stereoscopic 3DTV channel in the United Kingdom during 2010. Several consumer electronics manufacturers have also announced their intention to introduce stereoscopic television receivers during 2010.

An essential aim of this Report is to present a framework for a study of the various aspects of digital three-dimensional (3D) TV broadcasting systems¹ as outlined in Question ITU-R 128/6. It is intended to identify the issues that need to be addressed, and to encourage further contributions to WP 6C.

1 Motivations for the introduction of 3DTV broadcasting

Interest in the possibility of 3DTV in the home may be due in part to a new wave of 3D movies reaching the cinema. In spite of the need to wear glasses, 3D movies have proved to be popular, attracting large audiences who are prepared to pay a premium for the 3D experience.

This in turn is creating expectations of the possibly imminent arrival of 3D movies in the home through packaged media², such as DVD and Blu-ray. Movies are an important part of television broadcasting, and so it is natural to consider whether 3D movies might in due course be made available through broadcast means.

On the other hand, while the need to wear glasses has not been an impediment to the success of 3D-cinema, questions are raised about the suitability of glasses in the home environment. The current state of development of autostereoscopic displays for glasses-free viewing leaves much to be desired, although it is hoped that ongoing research will eventually lead to improved or even new forms of glasses-free display.

So today's motivation to explore the possibility of the introduction of 3DTV broadcasting may be seen partly as exploitation of the natural evolution of the phased delivery chain used for movies where feature films are first screened in the theatre, then go to the home in packaged media, and finally are made available on broadcast television. In addition, a pay television operator may also have an interest in offering premium content in 3D, whether movies or live events.

¹ Digital (3DTV) broadcasting is a television system that is designed to convey by broadcast transmission a more natural impression of depth to the scene that is being portrayed, by rendering spatially different views to each eye.

In its simplest form, the viewer is presented with a fixed or "static" stereoscopic view of the scene, while a more complex form of 3DTV enables the viewer to change the perspective of what is seen in discrete steps, by means of head movement. In its ultimate form, "holographic" three dimensional presentation would enable the viewer to change perspective through head movement in a continuous way that is comparable to natural sight in real life.

² Currently available Blu-ray and DVD packaged media use a rudimentary form of stereoscopic television, referred to later as a Level 1 system. The expectations are that a more sophisticated system will soon be available.

Lastly, although 3DTV might not currently be seen a "future alternative" or development of highdefinition television (HDTV), it is certainly possible that it could at least have a complementary role to other forms of 3D experience that are likely to become available in the home in the not too distant future.

2 Background to possible 3DTV systems

The fundamental means by which a 3DTV broadcast system today is capable of enhancing user's visual experience of three-dimensionality, compared to the broadcast of HDTV images, is by delivering stereoscopic image information to viewers in the home. 3DTV broadcasts must provide the signals necessary for generating images with different views of a scene to the two eyes of a viewer. By means of binocular fusion of the stereoscopic images, the 3DTV viewer can obtain an enhanced sensation of depth and an improved sensation of "presence" and "reality".

It is envisioned that the technology of 3DTV systems, as with all media systems, will develop and advance from one generation to the next, over a period of possibly many years. It may be anticipated that future generations will be likely to increase the amount of visual information provided, reduce the restrictive need for eyewear, and increase the freedom of movement allowed without negatively affecting the quality of the stereoscopic depth.

Thus, one method of classifying the various 3DTV systems is as follows:

Eyewear-based systems:

Those systems that are based on or targeted for "plano-stereoscopic" displays, whereby left and right eye images are presented independently to the two eyes using various methods that require eyewear to isolate the two views of a given scene.

Multiview autostereoscopic systems:

Such systems that are targeted for "plano-stereoscopic" (or non volumetric) displays whereby left and right eye images are presented independently to the two eyes, using various methods that allow two views of a given scene to be isolated without the need for eyewear. In addition, this generation of systems provides multiple views of a scene such that viewers can freely change their viewing angle and have access to visual scene behind objects.

Integral imaging or holographic system:

Those systems that are based on object-wave recording (holography) or integral imaging and are targeted at the simulation of a light field generated by an actual scene. Thus, freedom of viewing position without the hindrance of eyewear is provided. In addition, the light field provides the visual information (focus cues) for adjusting the ocular lens so as to focus correctly at the same distance as the convergence distance. This provides more natural viewing than the systems of the previous generations that requires maintenance of focus at the display screen irrespective of convergence distance.

3 A hierarchical structure

Current proposals for 3DTV signal formats can be seen as forming a hierarchical structure, which correspond to different constraints and requirements. This is given in diagrammatic form Fig. 1. This hierarchy might be used in future for any draft Recommendation for 3DTV by the ITU-R found to be required.

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FIGURE 1

Matrix of signal formats for 3DTV

Compatibility level

Conventional HD Service Compatible (CSC)	2D HD + MVC ⁽¹⁾ (i.e. MVC)	2D HD + MVC ⁽²⁾ (i.e. MVC) (Depth, occlusion,	
Level 4	(L, R formed by matrixing)	transparency data)	
HD Frame-Compatible Compatible (FCC)	Frame compatible plus MPEG resolution extension, for example SVC ⁽³⁾		
Level 3			
Conventional HD Frame Compatible (CFC)	Frame compatible (L, R in same HD frame)		
Level 2			
Conventional HD Display Compatible (CDC)	Optimized colour anaglyph		
Level 1			
	Plano-stereoscopic profile	Multiview p rofile	Object wave profile
	1st generation 3DTV	2nd generation 3DTV	3rd generation 3DTV

Generation profile

⁽¹⁾ MPEG-4 AVC Stereo High Profile – a subset (to be published) of MPEG Multiview Video Coding (MVC), annex H to ITU-T Recommendation H.264.

⁽²⁾ It is understood that ISO/IEC JTC/SC29/WG11 intends to address this form of extension to MVC.

⁽³⁾ Annex G to ITU-T Recommendation H.264.

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The principle of the hierarchy is that each box in the matrix in the diagram defines a type of signal, and this would correspond to the needs of a generic type of receiver. This is somewhat similar to the concept used for ISO/IEC JTC1 MPEG standards, though there are differences. Upper levels are intended to be "backward compatible" with lower levels, with one exception which is explained later.

Though different 3DTV display technologies today have different advantages and disadvantages, the hierarchy is essentially independent of the type of display used. Research and development, and market forces should allow 3DTV displays and technology to evolve and improve, while preserving the public interest for interoperability.

The hierarchy needs to cope with a range of circumstances, from where existing receiving equipment must be used intact (though glasses are used), to where some new elements (displays) are acceptable, to where both new receivers and displays are acceptable.

The quality of the 3DTV will be influenced by the quality of the individual left-eye and right-eye signals, and because of this, 3DTV may be most effective for the higher quality environment rather than the SD-TV environment.

Broadcasters may choose to use available 3DTV technology, and find the limitations acceptable, bearing in mind the gains, or they may prefer to wait for future technology which will have fewer limitations. It seems desirable that ITU-R should provide guidance for both.

3.1 Technology generations

In Fig. 1, the x-axis relates to the **system "generation"**. We may expect basic 3DTV technology to evolve in the decades ahead. The pattern of evolution is that we move from viewing a single stereo view with glasses, then to viewing with greater freedom for head movement, finally to viewing as we do normally ("natural vision").

Broadcasters may decide to begin broadcasting with earlier technology generations (with its limitations), or to wait for future generations.

First-generation technology is based on the capture and delivery of two views, one for the left eye, and one for the right eye. There is a single "binocular disparity" or binocular parallax. There are limitations with such systems, compared to "natural vision". With careful production, delivery, and display, effective results can be achieved. Usually, special glasses are used for viewing, though viewing without glasses (auto-stereoscopic) viewing is also possible.

Second generation technology is based on capture and delivery of multiple views. This allows multiple binocular disparities which makes the viewing experience closer to "natural vision". Normally viewing will be done without glasses on auto-stereoscopic displays.

Third generation technology is based on the capture and delivery of the "object wave", as is done in a simple way today with holography. The development of such systems is many years away at the moment.

We cannot predict with certainty whether, when, or if, the higher generations will be developed. But, we may note that often generation steps occur about every ten years or so, and that there can be a long lead time from idea to commercial exploitation.

3.2 Compatibility levels

The levels, or y-axis, in Fig. 1 relates to **compatibility levels**.

Level 1 relates to signals which provide for a system which does not require any new equipment by the viewer with the exception of glasses. This level is said to be HD conventional display compatible (CDC).

Level 2 relates to signals which provide for systems that require a new display but not a new set top box. This level is said to be conventional HD frame compatible (CFC). The 3DTV signal appears as a single HD signal to the set top box, which passes it through to the (new) display, where it is decoded and displayed as left and right pictures. If a 2D service of the same channel or programme is needed, it can in principle be provided as a conventional HD signal simulcast, provided there is sufficient spectrum. The left-eye and right-eye signals do not have the same "spectral occupancy" as conventional HD signals – some has to be sacrificed.

Levels 3 and 4 relate to systems which require a new set top box and a new display, but which offer a normal HD spectral occupancy left-eye and right-eye 3D service. Level 3 is said to be frame-compatible compatible (FCC), because it is an extension of Level 2. Level 4 is said to be conventional HD service compatible (CSC) because an existing 2D set top box will find, in the

incoming multiplex, a conventional 2D HD signal which it can pass to a conventional display as a 2D picture.

3.3 Matrix points

Level 1/first-generation profile

The generic receiver here, for which the signal is intended, is a conventional HDTV receiver. The signals transmitted are based on a wavelength division multiplex and matrixing of the left-eye and right-eye signals, and a choice of complementary primary colour separation. For example, the "ColorCode" system has been broadcast in Europe and North America using Red/Green in one eye, and Blue for the other eye. Other sets trialled have been Red vs. Green/Blue, or Green vs. Red/Blue. The exact matrixing and choice of complementary colours can be left to market developments because a conventional receiver and 3-primary display is used, though in the light of experience ITU-R may be able to report on options.

Level 2/first-generation profile

The generic set top box here for which the signal is intended is a conventional HDTV set top box. But the 3D display needed is new and must have the capability to interpret an HD frame as left-eye and right-eye pictures. There are alternative ways to arrange the left-eye and right-eye signals to appear to the STB to be a single frame. The three principal methods (which involve sub-sampling) are the side by side (SbS), the over and under method (OaU), and the interleaved sample (IS), checkerboard or Quincunx method (of which there are variants). It is understood that BSkyB in the United Kingdom will probably use the SbS method (2x1080i/960) subject to discussions on licence issues. It would be very valuable to the public to identify a single CFC method for broadcasting. At minimum a common method of signalling the format is needed.

This matrix point may be of particular value to broadcasters who manage a large existing population of set top boxes which must not be disenfranchised by the 3DTV broadcasts, and for whom additional delivery channels are available which can be used for 3DTV.

Simultaneous delivery of a 2D version of the same programme, if needed, requires a simulcast of a conventional HDTV signal.

For this and other Levels, the issue of "creative compatibility" of a 3DTV signal and a 2D TV version needs to be considered.

Level 3/first-generation profile

The generic set top box (or IRD) for which the signal is intended here is a new set top box which is able to decode a Level 2, Frame Compatible image, and also decode a resolution enhancement layer, using for example, MPEG SVC (scalable video coding), yielding normal spectral occupancy L and R HD images for output to the display. This approach allows existing Level 2 transmissions to be compatibly improved to normal HD spectral occupancy, with the improvement becoming available by replacing the population of conventional set top boxes with the new set top boxes. Note that unless all set top boxes are replaced, it could still be necessary to simulcast a 2D version of the programme for the 2D audience. Set top boxes (or IRDs) for this level would decode Levels 1 and 2 also.

Level 4/first-generation profile

The generic set top box here is also a new set top box (or IRD) which is able to decode an MPEG MVC signal conforming to the ISO/IEC JTC1 MPEG specification. The signal is arranged so that a conventional set top sees a single 2D HD signal which can be passed to a conventional display as a 2D service. New set top boxes (or integrated receiver/displays) recognize the additional information in order to decode a second view and provide two output signals L and R, to the

display. Set top boxes for Level 4/first-generation profile include capability for Level 2 decoding (but, depending on market conditions, not complete Level 3 decoding including extension).

This matrix point may be particularly valuable to operators of terrestrial broadcasting services, where channels are scarce, and where it is necessary to provide both a 3D and 2D service from the same channel.

Level 4/second-generation profile

The generic receiver here for which the signal is intended is also a new set top box which is able to decode the 2D HD plus depth format as specified by the IEC/ISO JTC1 MPEG specification. The display is normally a multiview auto- stereoscopic display. Such set top boxes would also decode Levels 1, 2, and 4 of the first-generation profile.

Other matrix points are left empty for the time being.

4 First-generation 3DTV

It is not currently envisaged that a complete transition from 2D to 3DTV broadcasting will take place in the foreseeable future.

Rather, there is a need to first properly assess the viability of first-generation 3DTV broadcasting. This might perhaps take the form of various 3DTV programme content being made available to the public in a limited ad hoc manner, perhaps just a few hours per week. This could align with other research that is required, such as on the possible effects of eye strain and to assess whether there is acceptance of prolonged stereoscopic viewing. This may be considered as a test phase.

The business models are not the same for pay television and for free-to-air broadcasters, and so the acceptable solutions for first-generation 3DTV broadcasting are anticipated to be different, as explained in § 3 above.

Two variants of first-generation systems may therefore be required for use in different situations: where a service is to be delivered only to viewers with 3D displays; secondly, where the primary audience continues to be viewers receiving an existing 2D service, and it is wished to make use of the same transmission channel to deliver at least some programmes in 3D.

Two techniques are available to satisfy the above conditions:

A "frame-based" approach: package the left and right images into an existing HDTV frame.

There are several possible permutations of placement of the left-eye and right-eye images within the frame:

- side-by-side;
- over/under;

1

- line/column interleaved;
- checkerboard/quincunx.

There is also the potential to add layering techniques to restore the resolution that would otherwise be lost by the placement of two images within a single frame.

A frame-based service would not be directly viewable by existing 2D viewers.

For a multichannel pay television operator, the priority is likely to be to exploit the existing infrastructure in order to deliver 3DTV content to a group of subscribers. Indeed, such an operator could be in a position to do so without impact on services already being delivered to viewers. In this situation, a frame-based solution may be attractive.

A free-to-air operator with access to only limited transmission capacity might require to continue to use existing transmission channels to reach the general 2D audience. In this situation, a frame-based approach would not be suitable.

2 A 2D compatible method

This approach requires that additional information be conveyed in order to reconstruct the second image for suitably equipped 3D receivers.

There are several possibilities for making available the additional information needed to reconstruct the second image:

- simulcast;
- 2D + "delta" (data coded to represent the difference information between left-eye and right-eye images);
- 2D + DOT (data to represent depth, occlusion and transparency information).

A "2D + depth" coding scheme could allow multiple views to be generated for presentation on autosteroscopic displays.

The 2D compatible approach allows existing viewers to continue to watch a 2D service. Those viewers wishing to receive 3DTV transmissions would need specially equipped receivers.

As an example, Korea's terrestrial broadcasters, KBS, MBC (Munhwa Broadcasting Corp.), SBS and EBS (Educational Broadcasting System), have prepared for 3D trial broadcasting from October 2010 using dual stream coding (left image with MPEG-2, right image with AVC/H.264) at a resolution of $1\,920 \times 1\,080$ interlaced 30 fps. Unlike some countries that have already tested 3D TV broadcasting, they will offer the service through terrestrial networks. Furthermore, Korea will be the first country in the world to offer a full HD 3D broadcasting service. In addition, cable broadcasters CJHelloVision and HCN and Korea Digital Satellite Broadcasting, will also take part in the 3D trial broadcasting service.

5 Future generations of 3DTV

Advanced forms of autostereoscopic display in conjunction with multiple camera systems are under study with the intention of allowing viewers to set their preferred viewpoint and to change it continuously in a range determined by the number of cameras and their allocation, for example so-called "free viewpoint television", see Annex 3. This approach can retain backwards compatibility with the displays used for first-generation 3DTV.

There are also studies on possible new forms of "object wave recording" that could allow three-dimensional television images to be presented in a way that represents viewing the physical light in a virtual a space, perhaps using an advanced "integral" method or a holographic system. Such schemes are in the research phase. These studies are to be encouraged, as they promise to lead to the eventual realization of the ultimate goal of presenting images to viewers that are virtually indistinguishable from natural real-world surroundings. To achieve this, new types of advanced volumetric display will be required. It is currently uncertain when this technology might become available: it is likely to be many years in the future.

6 Expected bandwidth requirements for a first-generation system

In the case of a first-generation "2D compatible" system of broadcasting, some additional bit rate will certainly be required. In the extreme, 100% extra would be required for a second simulcast video channel. In practice this would be likely to be somewhat lower using a supplementary data stream for reconstruction of the second video image.

In the case of a "frame compatible" system, if it is accepted that the L and R images contain less spatial resolution than for a 2D system, then in principle no extra bit rate is required compared to the transmission of a normal 2D service. In practice, it is understood that operators plan to use broadcast bit-rates which are at the high end of current practice. It may nevertheless be argued that because this approach does not provide a 2D-compatible service, a completely new transmission channel is required, i.e. 100% extra capacity. However, in the circumstances of a multichannel operator this might not necessarily be a constraint.

It is currently unclear what the quality differences would be between these approaches, and there will inevitably be a trade-off between bit-rate and quality. Independent testing would be desirable.

The human visual perception can be exploited to reduce bandwidth requirements. For example:

- filtering (blurring) in one eye (switching on scene cuts);
- asymmetrical coding.

The 2D + depth approach offers the prospect of considerable bit-rate saving. However, a costeffective method for depth map creation is not easy to obtain and is still an active area of research.

In the case of more advanced multiview schemes, multiview coding requires multiple synchronized video signals to show the same scene from different viewpoints. This leads to large amounts of data, but typically a larger amount of inter-view statistical dependencies than for stereo.

Last, but not least, independent testing using a standardized testing methodology is needed in order to accurately quantify how much extra bit rate would be needed, using a range of representative 3DTV source material.

7 The 3DTV broadcasting chain

The end-to-end broadcasting chain from image source, programme production, delivery and display may be illustrated as follows:



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The implications for the following individual elements of the broadcasting chain should be considered:

7.1 Image source methods

There are three main approaches to sourcing 3D programme material in use today. These are: stereo camera, CGI, and conversion from 2D video.

Most 3D video captured presently use stereo camera rigs. Some test footage has been captured using stereo cameras coupled with a rangefinder. Rangefinders are usually laser or infrared-based and attempt to provide depth maps for a given scene. The depth maps are prone to numerous errors due to a number of issues, such as poor accuracy, speculars, translucent objects, transparent objects and reflections. Another capture method that has had some testing is multi-camera rigs. These have a large number of cameras that provide a number of views. This method works well for capturing several views. However, the complicated rigs plus the large amounts of data currently prohibit widespread use of multi-camera rigs.

Computer generated content is typically considered the easiest method of stereo generation. The rendering system can either render one or more related views depending on the application. In addition, the Z buffer, which represents the distance to the screen of various objects, can be exported as a depth map. In either case, computer generated data can be used for stereoscopic production or for multiview production.

Finally, 3D video can be created by taking conventional 2D video and adding depth information. The normal process is to deconstruct the 2D image into a series of objects (also known as segmentation), assigning relative depth to each object, then filling in occluded areas. Human visual perception can also be exploited in the processes for converting from 2D to 3D. The creation of a depth map from a 2D allows for the creation of multiple views, through a rendering process that incorporates techniques of covering disoccluded regions.

7.2 Characteristics of signals in the studio

Without coding or compression, the baseband required for a two-channel 3DTV system, with HD resolution for each eye, is twice that required for a HDTV system. However, the actual requirements will depend on the format of the signals of the 3DTV system.

- How much information is involved?
- Can signals be handled by existing equipment and interfaces?
- Would new interfaces be required?

The answers to the above questions can be expected to vary according to the form of the 3DTV system.

Some form of metadata for first-generation systems are required to ensure that the left-eye and right-eye views are correctly identified. This may be based on either explicit or implicit information. For example, in the side-by-side format, whether the image on the left consists of the left-eye or right-eye view, and the sampling structure used, has to be known. Synchronization of the left-eye and right-eye views is also needed to ensure that there are no errors in timing, such as with the above-below format. Some of these signals might be able to be handled by existing equipment and interfaces but others might not.

Also, control signals are required for active eyewear that has to synchronize its operation with the view that is being displayed on the screen.

7.3 **Programme production**

Equipment is required that must handle recording, editing, effects, and postproduction.

The effect of the introduction on first-generation 3DTV on existing Recommendations that apply in the studio production environment will need to be considered.

Suitable provision will need to be made for monitoring the quality of the 3DTV at the point of origination and at appropriate points in the production chain.

One satellite broadcaster's technical guidelines, the prime objectives of which are to deliver content of both a high technical quality and of high production values may be seen at <u>http://introducingsky3d.sky.com/a/bskyb-3d-tech-spec/</u>.

Further study is required.

7.4 Emission

3DTV signals may need to be encoded in ways that are appropriate to their transmission within the existing 6/7/8 MHz terrestrial transmission channels, and also by existing broadcast satellite services.

Different techniques are likely to be required that are appropriate to each of these situations, and according to the requirements of the broadcaster as indicated in §§ 4 and 5.

7.5 Display

There are known to be three fundamental approaches:

- viewer wears glasses;
- without glasses (auto-stereoscopic);
- headmounted display.

With a headmounted display, the left and right eyes are presented with the left-eye and right-eye images of a stereo pair. This may be appropriate for video games, but is unlikely to be appropriate for viewing of broadcast television. It is an individual viewing experience and is not suitable for collective (e.g. family) viewing of broadcast television.

Within these broad categories, various approaches may be possible. In many cases, 3DTV presentation relies on some form of eyewear or headgear that the viewer must wear in order to discriminate between left-eye and right-eye images:

- Anaglyph: a stereoscopic effect can be obtained by displaying images in which the presentation screen simultaneously displays two differently-filtered coloured images, (typically red for the right-eye image and cyan for the left-eye image). These are viewed through correspondingly-coloured glasses. One difficulty with this solution is that the viewer may feel compelled to remove the coloured glasses when looking away from the presentation screen. In addition, the programme presentation will necessarily provide an inferior colour rendition.
- Polarized glasses: this solution makes use of cross-polarizations for the right-eye and the left-eye images of a stereo pair; the images are watched through correspondingly cross-polarized glasses. One solution to display such cross-polarized image uses a "tiled" display of alternating tiles for the first and second image of a stereo pair. The tiled display is covered by an identically tiled polarized mask, with alternating tiles being cross-polarized. When viewed through cross-polarized glasses, separate views will be presented to the left and right eyes of the viewer. One problem with this solution is that the presentation of stereo images at HDTV resolution requires a more expensive display providing at least twice the horizontal resolution of HDTV.
- Shuttered glasses: the two images of a stereo pair are time-interleaved on the screen, and viewed through special glasses in which the left and right eye lenses are shuttered in turn, following the switching cycle of the left and right images on the screen.

While it seems inevitable that, at least to begin with (and possibly for many years) 3DTV viewing would require that viewers to wear glasses, first-generation 3DTV broadcasts could nevertheless continue to be viewed on more advanced improved forms of autostereoscopic display as the technology progresses.

8 Production grammar

Poor quality stereoscopic television could "poison the water" for everyone. There is a risk that 3DTV becomes associated with eye strain if stereoscopic content is poorly realized – whether due to inappropriate production grammar or due to inadequate technology for delivery. This has happened before in the cinema in the 30s, 50s, and 80s.

The production grammar of 3D often differs to 2D productions. Special care has to be taken in order to achieve a good 3D viewing experience. This can lead to some compromises for the 2D viewer. In some cases, a production might be optimized for 3D, with no intention that the 3DTV version be used for conventional standard- or high-definition television presentation.

It is understood that various recent trial 3DTV productions have provided useful learning experiences, and it is expected that further knowledge will be gained through ongoing trial productions and from services that have recently become available to the public. Live 3DTV production presents particular challenges. Live production nevertheless forms a regular part of the schedule of the recently introduced 3D service from United Kingdom pay television operator BSkyB.

9 Psychophysical aspects of viewing stereoscopic images

Before attempting to implement new broadcast schemes, it is necessary to gain a full understanding of the results of psychophysical studies in order to understand the effects to which the viewer is subjected and the performance that is required of the main equipment in these systems.

There are a number of issues to be studied before the effects of viewing three-dimensional images on human perception and visual functions can be fully understood.

Annex 4 identifies some key study items on the psychophysical aspects of stereoscopic television systems. It also includes the results of studies related to the naturalness and unnaturalness of stereoscopic video, and the evaluation of visual comfort based on an analysis of parallax distributions within certain frames.

9.1 Visual fatigue and other possible health hazards

An important problem of current stereoscopic television, which is common to all the approaches currently implemented, is that they present stereoscopic images on a single surface (the display screen), giving rise to a potential conflict between "vergence" (the eye movement to point both eyes to the same point on the screen) and "accommodation" (the action by which the "lens" in the viewer's eye focuses on that point). It has been documented in the medical literature that this

conflict can cause viewer's discomfort, eye fatigue, headache and possibly other health hazards notably if the viewing continues for an extended period of time^{3, 4}.

Such effects have been noticed in some recent trial broadcasts, For example, one of the terrestrial broadcasters in Korea, SBS (Seoul Broadcasting System) broadcast South Africa World Cup Soccer Games in 3D from 11th June 2010. In a survey of nearly 100 viewers, 75% expressed satisfaction with the trial 3DTV broadcasting service. However, the survey showed that 30% of the viewer felt dizziness, double image and eye fatigue.

A 3DTV Project Group (PG806) has been established in Korea with the aim of development of 3DTV broadcasting specification and viewing safety guideline. Working Group WG8062 is focusing on the development of a 3DTV viewing safety guideline for display, contents, viewing condition, and viewer parameters. A first version is planned to be completed by the end of 2010, and will continue to be updated until 2012.

Recent actions taken by the Italian Health Ministry, related to the use of 3D spectacles by the public attending cinema presentations of 3D movies, are described in Annex 5.

Factors that affect 3D viewing comfort also include inter-pupillary distance, intra-scene disparity range, and the speed of depth change of objects in the scene. In addition, rapid cuts between shots of differing depths and changing depths with zoom or pans are known to cause viewer discomfort. Some of these techniques are widely used in 2D production but might cause discomfort when viewed in 3D. Due to these factors, 3D production techniques tend to create 2D video that might be considered by 2D viewers as boring. This is the reason 3D productions to date have been different from the 2D productions of the same event or release. It is widely known that current 3D movie releases are editorially different the 2D releases.

10 Assessment methodology

Although a method for subjective assessment of image quality and depth quality is provided by Recommendation ITU-R BT.1438 – Subjective assessment of stereoscopic television pictures, the type and visibility of artefacts peculiar to stereoscopic images have yet to be systematically identified and studied. Furthermore, the various methodologies and formats have to be taken into consideration.

The development of an appropriate assessment methodology, in conjunction with a common set of reference source material is of the utmost importance for evaluating 3DTV systems. It is understood that PSNR results might not be indicative of the effect of artefacts, and that new metrics will need to be considered. Major issues concern the identification of the factors that contribute to viewing discomfort and the development of proper metrics for measuring levels of discomfort. It is

³ See for instance: K. Ukai & P.A. Howarth "Visual fatigue caused by viewing stereoscopic motion images: background, theories and observations" – Elsevier B:V., 2007, which states, *inter alia*, "Viewers should be careful to avoid viewing stereoscopic images for extended durations because visual fatigue might be accumulated.

They should be ready to stop immediately if fusion difficulties are experienced.

Hardware/software manufacturer should avoid unnatural image presentations, such as images that diverge further than infinity, large binocular disparity in the central visual field or around the objects that are the centre of the viewer's attention, difference of size and colour, unequal distortion between binocular images since they may cause fusion difficulty".

⁴ Masaki Emoto, Takahiro Niida, and Fumio Okano – "Repeated Vergence Adaptation Causes the Decline of Visual Functions in Watching Stereoscopic Television", Journal of Display Technology, Vol. 1, No. 2, December 2005.

especially urgent to not only seek a metric for the measurement of viewing comfort, as this is a major concern for most users and providers alike, but also to seek a methodology for testing viewing comfort for both short-term and long-term viewing.

Visual comfort, image quality and depth quality are major perceptual dimensions that both users and programme providers are interested in. However, the value of routine testing of other perceptual dimensions, such as "presence", "sensation of reality" and "naturalness", should also be investigated. It is likely that new metrics and methodology are required. Methodology is also required to compare the performance of various approaches to the transmission of 3DTV signals and effects of bandwidth reduction.

11 The viewing environment

The effect of the viewing environment is fundamental on the perception of depth and to the quality of the overall viewing experience. The following situations should be considered:

- the studio environment;
- the home environment.

In particular, in conjunction with viewing distance, picture size and subtended viewing angle play a role in the three-dimensional effect as perceived by the viewer. This might have implications on the way in which 3DTV should be produced and displayed.

12 User requirements

These are currently not fully understood.

At its May 2009 meeting, WP 6C decided to carry out a survey on the aspirations of the ITU Membership on 3DTV broadcasting. The survey was carried out between July 2009 and October 2009. All those who responded considered that there is a need to discuss with standards bodies, such as the IEC, the provision of minimum requirements for 3DTV receivers which match a future 3DTV broadcast system. In addition all respondees considered it very important/essential for a 3DTV system to have the same format as packaged media (e.g. HDTV capacity discs).

13 Performance requirements

The overall performance requirements need to be identified in sufficient detail in order to orient the choice of the appropriate technologies for a new 3DTV system.

A preliminary list of possible requirements is listed in Annex 6. This has been gleaned from contributions made to WP 6C since October 2008.

It is hoped that future contributions will provide clarifications and/or additional factors that should be considered.

14 Organizations with initiatives in 3DTV

A wide range of research, standardization, and trade associations are currently active in investigating aspects of 3DTV. A non-exhaustive list is attached in Annex 1.

15 Conclusions

Without an orderly approach to the standardization of 3DTV broadcasting systems, even for an initial test phase, various *de facto* standards will become established. There is a risk that subsequent implementation of 3DTV broadcasting could become more difficult.

Furthermore, actions likely to be taken by the gaming and optical media (Blu-ray) industries could have a significant impact on the capabilities of widely deployed consumer equipment.

It is also not known what the consequences might be of decisions on the future 3D-capabilities of interfaces to displays if these are taken in the absence of agreed requirements for 3DTV broadcasting systems.

It is anticipated that guidance will be desirable covering the following:

- quality assessment methods for 3DTV systems;
- reference 3DTV source materials for use in subjective tests;
- requirements for the broadcasting chain;
- requirements for production and production grammar;
- psychophysical aspects related to viewing of stereoscopic images;
- requirements first-generation 3DTV systems.

In addition, an important issue for further study is an understanding of bit-rate requirements for first-generation 3DTV broadcasting systems, for both the frame-based and compatible 2D approaches.

Referring to the matrix of signal formats described in Fig. 1, the most critical matrix points that might need to be standardized are the first-generation Levels 2 and 4 points to the maximum extent possible, but certainly regarding signalling.

Another critical issue is to try to align the matrix with the formats used for packaged media.

Further contributions to WP 6C are invited on the above and related topics.

Annex 1

Organizations with current initiatives in 3DTV

1 ISO/IEC JTC1/SC29/WG11

In July 2009 it was planned to finalize the specification of carriage of MVC over MPEG-2 systems, as well as extensions to the file format specifications to accommodate multiview video.

Work is also proposed to begin on a new 3D video (3DV) format that aims to support advanced stereoscopic display processing and auto-stereoscopic displays.

It is also understood that amendment to ISO/IEC 14496-10 are to include a spatially interleaved frame supplemental enhancement information (SEI) message to signal the type of interleaving in a frame-based scheme.

2 ITU-T Study Group 9

ITU-T SG 9 has recently initiated work items to develop draft new Recommendations on subjective assessment methods for 3D video quality and on display requirements for 3D video quality assessment. In addition, studies are being progressed on scalable view-range representation for free viewpoint television (FTV).

3 ITU-T Study Group 16

The multiview coding extension of Recommendation ITU-T H.264 | ISO/IEC 14496-10 MPEG-4 AVC has proceeded to AAP Consent under ITU-T Recommendation A.8 approval process.

4 **3DTV** – Network of Excellence

See: <u>www.3dtv-research.org</u>.

5 **3D4You – Content generation and delivery for 3D television**

3D4You is a project funded by the European Union under the information and communication technologies (ICT) Work Programme 2007-2008, a thematic priority for research and development under the specific programme "Cooperation" of the Seventh Framework Programme (2007-2013). Project website: <u>http://www.3d4you.eu/index.php</u>.

6 SMPTE

In August 2008, SMPTE formed a Task Force on 3D to the Home. This completed its work with publication of final report in March 2009. The report is available to SMPTE members, and also from <u>http://store.smpte.org/product-p/tf3d.htm</u>. The Recommendations include standardizing a "3D Home Master", based on the requirements developed by the Task Force. SMPTE is starting work on the specifications.

7 The Digital Video Broadcasting Project

Technical work in Digital Video Broadcasting Project (DVB) is driven by commercial requirements. Following completion of a study mission to investigate the possible need for 3D activities, further activity has led to the publication of "DVB commercial requirements for DVB-3DTV" (DVB Document A151, July 2010). This addresses "frame compatible" 3DTV services over HD broadcast infrastructures. Work has started on considering a second phase of "2D service compatible" commercial requirements.

8 The Blu-ray disc Association (BDA)

See: <u>http://www.blu-raydisc.com</u>.

9 HDMI Licensing, LLC, has announced the release of HDMI specification 1.4

See: http://www.hdmi.org/index.aspx.

10 Consumer Electronics Association

The Consumer Electronics Association (CEA) has established a 3D Task Force. This is considering interfaces between consumer sources, sinks, repeaters, converters, and glasses. They are also considering what is needed for "3D READY" products. It is proposed to develop standards for 3D glasses, including interface, signalling, setup, control and polarization. A project is being considered to update CEA-861 to carry 3D content.

11 The 3D@Home Consortium

This comprises around 40 members, with the aim of speeding the commercialization of 3D video into homes worldwide.

See: <u>http://www.3dathome.org</u>.

12 Association of Radio Industries and Businesses

The Association of Radio Industries and Businesses (ARIB) has established a working group for researching 3DTV broadcasting in 2008.

See: http://www.arib.or.jp/.

13 Ultra-realistic communications forum

The Ultra-realistic communications forum (URCF) is a forum established by the organizations from industries, government and academies, with the aim of promoting the R&D of ultra-realistic communications.

See: http://www.scat.or.jp/urcf/.

14 **3D** Consortium

The 3D Consortium was established in 2003 and comprises 47 members from 3D industry. Its main focus is on stereoscopic 3D.

See: <u>http://www.3dc.gr.jp/</u>.

15 Consortium of 3-D image business promotion

The Consortium of 3-D image business promotion was established in 2003 and comprises 49 members.

See: <u>http://www.rittaikyo.jp/</u>.

16 Japanese Ergonomics National Committee

Japanese Ergonomics National Committee (JENC) is in charge of the national preparation for ISO.TC159.

See: <u>http://ergonomics.jp/jenc/index.html</u>.

17 Telecommunications Technology Association

In Korea, Telecommunications Technology Association (TTA) has established a 3DTV Project Group (PG806), with the aim of development of 3DTV broadcasting specification and viewing safety guideline. 3DTV PG consist of two Working Groups; WG8061 for the development of 3DTV broadcasting specification and WG8062 for the development of 3DTV viewing safety guideline.

See: http://www.tta.or.kr/.

Annex 2

Historical background on the development of stereoscopic and 3D television systems

Document 6C/92 describes the present state of three-dimensional (3D) TV broadcasting studies in the Russian Federation:



Annex 3

Introduction to free viewpoint television

See Annex 1 to Annex 6 to Document 6C/69:



Annex 4

Psychophysical studies on three dimensional television systems

Summary

Before attempting to implement new broadcast schemes, we must gain a full understanding of the results of psychophysical studies in order to understand the effects to which the viewer is subjected and the performance that is required of the main equipment in these systems.

There are a number of issues to be studied before we can fully understand the effects of viewing three dimensional images on human perception and visual functions. For the success of three-dimensional television broadcasting, all parties concerned, including broadcasters, producers, manufacturers, and regulators, should be well informed of the effects.

The psychophysical aspects of viewing stereoscopic images have been extensively studied in Japan (Document 6C/338). This Annex provides some key study items on the psychophysical aspects of stereoscopic television systems.

In the Attachment, two research achievements from studies carried out in Japan are reported (Document 6C/406): the first is related to the naturalness and unnaturalness of stereoscopic video, and the second to the evaluation of visual comfort based on an analysis of parallax distributions within certain frames.

It is planned to provide further results of studies as these become available.

1 Psychophysical studies of stereoscopic imaging systems – key items for study

The following sections describe the key items for which further study is encouraged:

1.1 Naturalness and unnaturalness of images

1. Theoretical analysis of spatial reproduction characteristics of images taken by 3D cameras

It is of fundamental importance to understand precisely how a real space is converted into a stereoscopic image space by a camera. In particular, the reproducibility of a stereoscopic image space should be analysed in terms of different settings of the lens axes of 3D cameras.

2. Size distortion

The reproduction magnification ratio of an object at the shooting distance (the perceived size) varies with the imaging and display conditions. The resulting distortion in size may make an object be perceived as unnaturally small; this is called the "puppet theater" effect.

3. Depth distortion

The imaging and display conditions may reduce the reproduction magnification ratio of the depth direction and distort the perception of objects with visually imperceptible thicknesses. This is called the "cardboard" effect.

1.2 Viewing comfort and discomfort

1. Differences in size, verticality, inclination and brightness, and cross-talk

Viewers may not feel comfortable viewing left and right images that have size, verticality, inclination, and brightness differences. Cross-talk between the left and right images may also have an impact on viewing comfort.

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2. Psychological factors and the parallax distribution

The fundamental relationship between psychological effects brought about by 3D images and factors related to fatigue should be studied. In particular, "ease of viewing" and "sense of presence" may be key psychological factors. Attention should be paid to the distribution of parallaxes in the stereoscopic images. From the correlations between psychological factors and the parallax distribution, we can grasp the essential characteristics of stereoscopic images, e.g., the sense of presence they convey and their ease of viewing (visual discomfort).

3. Superimpositions within 3D images

With regard to superimpositions in a two-dimensional image, we only have to think about exactly where to display it on the screen. In the case of a stereoscopic image, however, we also need to pay attention to the depth of the superimposition. If we could find a preferred position for superimposition for stereoscopic images, we will be able to use it for actual program production.

4. Change in parallax distribution during scene changes

The parallax distribution of stereoscopic images is discontinuous during scene-change frames, where the scene depth and perceived convergence distance change. We need to evaluate how these changes affect the visual discomfort experienced during viewing of stereoscopic images.

1.3 Visual fatigue caused by parallax 3DTV viewing

Visual fatigue caused by viewing stereoscopic motion images is a particular safety concern. Viewer's repeated adaptation to the discrepancy between eye convergence and accommodation causes a decline of their visual functions and results in visual fatigue.

1.4 Individual differences in the stereopsis function

Visual functions vary greatly from person to person, so it is essential to understand that there are individual differences before 3D broadcasts begin. For instance, there are limits to the binocular parallax of left and right images which a person can fuse into one image; when the parallax exceeds these limits, a double image is perceived. In this situation, depth perception collapses and viewing becomes extremely uncomfortable. For this reason, it is necessary to know the range of binocular parallax over which two images can be fused into one. However, individual differences are vast and will necessitate a study of the stereopsis function of many people.

1.5 Effect on young people

We must bear in mind that young people's sense of sight changes as they mature. Viewing of stereoscopic images possibly affects their visual functions in ways different from adults. It may be advisable that young children be cautioned about viewing stereoscopic images for extended periods of time.

22

Attachment to Annex 4

Psychophysical studies of geometrical relationships and parallax distribution in stereoscopic images

1 Introduction

Before attempting to implement new broadcast schemes, we must gain a full understanding of the results of psychophysical studies in order to understand the effects to which the viewer is subjected and the performance that is required of the main equipment in these systems. This text reports two research achievements.

The first is related to the naturalness and unnaturalness of a stereoscopic video. This investigation of the geometrical reproducibility of spaces raises issues about the quality of stereoscopic images as regards depth distortion and spatial distortion and shows that it should be possible to predict the occurrence of excessive parallax issues.

The second relates to the evaluation of visual comfort based on an analysis of parallax distributions within certain frames. The results of subjective evaluation tests indicate that the parallax distributions in images that are judged to be visually comfortable tend to lie within a fixed range.

These research achievements would be useful for establishing methods that can prevent viewer stress and enable the production of programs that can make effective use of depth information.

2 Geometrical relationships and naturalness (see Annex 1)

The reproduction of depth information is essential for people to gain a sense of three-dimensionality from a stereoscopic image. Depth distortion in the stereoscopic image can create an unnatural impression when the image is viewed.

In stereoscopic imaging, the object is imaged using two cameras. The arrangement of these two cameras can be classified into parallel configurations where the optical axes of the two cameras are parallel with each other, and intersecting "toed-in" configurations where the two optical axes are made to intersect. When using a parallel configuration, a stereoscopic image with no spatial distortion is obtained when the gap between the cameras is set equal to the gap between the pupils, the horizontal offset of the left and right images projected on the screen is equal to the gap between the pupils, and the camera's angle of view is equal to the expected viewing angle of the display. In such cases, the image is said to be viewed under orthostereoscopic (distortion-free) conditions. When actual program production and viewing conditions are taken into consideration, it is difficult to ensure that distortion-free conditions are always satisfied. If these conditions are not met, depending on the conditions, the spatial distortion of the stereoscopic image can cause unnatural effects such as the "puppet theater" effect and "cardboard" effect. The puppet theater effect is a phenomenon wherein the stereoscopic image of an object appears unnaturally thin.

The puppet theater (size distortion) and cardboard (depth distortion) effects are typical phenomena that are due to distortion of the reproduced stereoscopic image space.

Annex 1 presents a geometric analysis of reproduced stereoscopic image spaces and discusses the results and their relationship to the distortion of reproduced stereoscopic image spaces. The results of subjective evaluation tests that support these findings are also shown.

The discussion in Annex 1 relates to how the reproduced stereoscopic image space is affected by parameters such as the camera configuration (parallel or toed-in), display screen size, and viewing distance. This discussion is based on an investigation of issues associated with visual comfort/discomfort and visual fatigue as well as with naturalness and unnaturalness.

3 Parallax distribution and visual comfort (see Annex 2)

Finding a way to make the visual comfort of stereoscopic images a measurable physical factor is arguably one of the key issues in stereoscopic imaging research. Stereoscopic images convey depth information to the viewer by making use of the parallax between the images presented to the left and right eyes. If we could ascertain how the magnitude and distribution characteristics of this parallax relate to the visual comfort of the image, then this information would be very useful for the production of stereoscopic images.

As reported in Annex 2, parallax distributions were measured with a new parallax detection method and the relationship between the characteristics of stereoscopic images obtained from these results of measurements and the psychological visual comfort of these images were investigated.

How these parameters relate to the subjective visual comfort of stereoscopic images was studied by focusing on the average and range of the parallax distributions. As a result, it was shown that they both have a correlation with the visual comfort of stereoscopic images and that the range of parallax distributions in stereoscopic images appraised as visually comfortable was almost 60 pixels in HDTV image. It was also suggested that stereoscopic images tend to become more visually comfortable when the average value of the parallax distribution approaches zero (i.e. at apparent positions closer to the display screen).

4 Conclusion

We have reported on two studies relating to stereoscopic images, focusing on their geometric properties and the properties of parallax distributions within images. Each of these two studies highlighted the close relationship with naturalness/unnaturalness and visual comfort/discomfort, respectively. The visual fatigue and other possible health hazards induced in viewers by stereoscopic images are further problems that have not been touched upon in this Report.

Annex 1 to Attachment to Annex 4

Geometrical relationships and naturalness: Geometrical analysis of spaces reproduced by stereoscopic images

1 Theoretical analysis of reproduced spaces

A basic requirement for the design of stereoscopic systems is an understanding of the transformation from real space (the space in which an actual object exists) to reproduced stereoscopic image space (the representation of this space in a stereoscopic image). In this section, we analyse the distortion of reproduced stereoscopic image space on the basis of image shooting and display system parameters [5].

1.1 Model of shooting/display systems

The configurations of the image shooting and display systems analyzed here conform to the parameters shown in Fig. 3. The details of these parameters are shown in Table 1.



Shooting and display systems can typically be configured in two different ways depending on how the optical axes are arranged.

Parallel configurations (where the two cameras of the stereo camera are aligned parallel to each other) are characterized such that objects at infinity are displayed at infinity by maintaining a constant horizontal separation of H_c between the left and right images when they are displayed (see Fig. 4). As a special case, when the separation d_c between the cameras and the horizontal offset H_c between the left and right images are equal to the separation d_e between the viewer's pupils, and the lens angle θ_b is equal to the angle of view of the display screen θ_d , the real space is in theory reflected without distortion in the reproduced stereoscopic image space [3]. However, it is not always possible to satisfy this condition in broadcasting where a wide variety of different subjects are liable to be viewed under widely varying conditions.

Another optical axis configuration is the so-called toed-in configuration wherein the optical axes of the two cameras intersect (see Fig. 5). This configuration is characterized such that an object situated at the intersection of the optical axes appears at the depth position of the screen on which its stereoscopic image is displayed. It is also relatively easy to present a sense of depth for objects in the space in front of and behind the object at the intersection of the optical axes. By virtue of these characteristics, this method appears to be used in most stereoscopic programs.

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Parameters in shooting and display models

d_c	Camera separation
d_e	Eye separation
L_b	Shooting distance
L_c	Convergence distance
L_s	Viewing distance
L_d	Position of a stereoscopic object
α	Angles of view of lens
β	Viewing angle
θ_c	Camera convergence angle
θ	Convergence angle of eye
H_c	Horizontal gap between L and R images
W	Width of screen
W'	Width of virtual screen at the viewing distance in the shooting model
x'	Distance from the centre of the virtual screen at the viewing distance in the shooting model (see Fig. 3)



(distortion-free when $d_c = d_e = H_c$ and $\theta_b = \theta_d$)



1.2 Depth distance in real space and stereoscopic image space

If an object's depth position in real space (the environment where images are shot) and stereoscopic image space (the reproduced environment) are L_b and L_d , respectively, then the relationship between these values obeys the following formula using the parameters of Table 1 and the geometrical relationship of the system configuration shown in Fig. 3.

$$L_{d} = \frac{1}{\frac{1}{L_{s}} - \frac{a_{1} \cdot a_{2}}{L_{c}} + \frac{a_{1} \cdot a_{2}}{L_{b}} - \frac{H_{c}}{L_{s} \cdot d_{e}}}$$
(1)

In a parallel configuration, we can set $L_c \rightarrow \infty$ and $H_c = d_e$. In a toed-in configuration, we can set $H_c = 0$.

Table 2 shows the results of using Equation (1) to investigate how the depth position L_d in the reproduced image and the actual depth position (the original camera-to-object distance) L_b are expressed in systems with parallel and toed-in configurations.

In Table 2, no consideration is given to the keystone distortion of the image shape that occurs in toed-in configurations. In other words, this table shows the characteristics at the centre of the image where keystone distortion has little effect.

In the parallel configuration, L_b and L_d obey a proportional relationship regardless of the parameter settings. On the other hand, in the toed-in configuration, L_b and L_d are equal only for a certain specific combination of parameters ($L_c = a_1 \cdot a_2 \cdot L_s$), but otherwise have a non-linear relationship. The graph of Table 2 indicates that different characteristics are exhibited depending on the sizes of L_c and $a_1 \cdot a_2 \cdot L_s$.

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2 Size distortion

The size of the reproduced image of an object shot by a camera at a certain distance (i.e. the size of recognized objects) varies with the image shooting conditions and display conditions, but is generally subject to size distortion. When size distortion causes objects to appear unnaturally small, it is often referred to as the "puppet theater" effect [2].

2.1 Theoretical analysis

The puppet theater effect has various interpretations. Here, we will not concern ourselves with the perceived absolute size of the reproduced image. Instead, we will concentrate on cases where the size of objects appears to be unnaturally deformed in comparison with the foreground and background.

If W_b is an object's size in the real space and W_r is its apparent size in the stereoscopic image space (i.e., its perceived size based on its depth position), then the relationship between these values is expressed by the formula below, where a_2 has the value shown in Table 2.

$$W_r = \frac{L_d}{L_b} \frac{\tan\frac{\beta}{2}}{\tan\frac{\alpha}{2}} W_b = \frac{L_d}{L_b} \cdot a_2 \cdot W_b$$
(2)

Now let us introduce the magnification M_s of the reproduced image. As shown in equation (3), M_s expresses the apparent size change of objects, taking their depth position into consideration. It corresponds to the ratio of the size W_r of the reproduced image to the size W_b of the object in real space.

$$M_S = \frac{W_r}{W_b} \tag{3}$$

Table 3 shows the results of applying M_s to the parameters of the parallel and toed-in camera configurations shown in Table 2. In the parallel configuration, M_s is constant regardless of the camera-to-object distance L_b , but in the toed-in configuration, M_s varies with L_b . In the toed-in configuration, the sizes of two objects at different depth distances (i.e. background and foreground objects) can be perceived very differently depending on the combination of parameters, and this is liable to cause puppet theater effects in some cases.

TABLE 3

Reproduction magnification ratio of an object (Ms) In the case of the parallel camera In the case of the toed-in camera configuration: configuration: $Ms = -\frac{1}{2}$ Ms = $\frac{\underline{a_1 \cdot a_2}}{\underline{L_c}} + \frac{\underline{a_1 \cdot a_2}}{\underline{L_b}} \cdot \frac{\underline{L_b}}{\underline{L_b}}$ 1 In the case of the parallel camera configuration, the In the case of the toed-in camera configuration, reproduction magnification ratio is $1/a_1$. except where $L_c = a_1 \cdot a_2 \cdot L_s$, the reproduction magnification ratio of an object depends nonlinearly on the shooting distance and the background affects the perceived size of the object. Especially in the case of $L_c < a_1 \cdot a_2 \cdot L_s$, the Puppet Theater effect tends to be enhanced because the reproduced foreground is smaller than the background.

Analysis of magnitude distortion

2.2 Subjective evaluation tests

In the discussion of the previous section, we showed that an object's reproduced magnification M_s changes with various different parameters. Thus, when two objects (e.g. foreground and background objects) are reproduced at different magnifications, it is expected that unnatural phenomena such as the puppet theater effect will occur.

We tried to apply the geometrical discussion of the previous section to the results of subjective evaluation tests.

In the subjective evaluation tests, stereoscopic images were reproduced under a number of different imaging and display conditions, and the test subjects evaluated their subjective impressions of the object size [4].

For the evaluation images, we used images of a roughly life-sized mannequin (shown in Fig. 6) using three different configurations of shooting distances and camera lenses, each with three different distances separating the left and right cameras. This resulted in a total of nine different evaluation images. Table 4 lists the details of these imaging and display conditions. In these images,

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the foreground consists of the mannequin, and the background consists of a corridor doorway 4.5 m behind it. In each case, the depth position of the mannequin in the stereoscopic image was at the position of the screen, and the image was displayed life-size on a 120-inch screen.

The test subjects were asked to evaluate the subjective size of the reproduced stereoscopic image of the mannequin on the following five-grade scale:

- 5: Large
- 4: Somewhat large
- 3: Normal
- 2: Somewhat small
- 1: Small

FIGURE 6

Object used for subjective evaluation tests of puppet theater effect



TABLE 4

Shooting and display conditions used in subjective evaluation tests of puppet theater effect

conditions	1	2	3	4	5	6	7	8	9
contents	A			В			с		
the angles of view of lens α (degree)		51.3			27.0			18.2	
the distance to the foreground object (m)		3.0			6.0			9.0	
the distance to the background object (m)		7.5		10.5			13.5		
convergence distance Lc (m)		3.0	.0 6.0				9.0		
camera separation dc (mm)	65	95	125	6 5	95	125	65	95	125
viewing angle β (degree)					33.4				
viewing distance Ls (m)					4.11				
a ₁	1.00	1.46	1.92	1.00	1.46	1.92	1.00	1.46	1.92
a ₂		0.63			1.25	_		1.88	
Lc/(a1*a2*Ls)	1.16	0.79	0.60	1.17	0.80	0.61	1.16	0.80	0.61
Ep	1.21	0.61	0.01	1.11	0.81	0.52	1.07	0.87	0.68

FIGURE 7 Correspondence with subjective evaluation scores



We used the ratio E_p of the foreground and background magnifications $(M_s^{(F)} \text{ and } M_s^{(B)})$ as a predicted value of the puppet theater effect. Here, the depth position of the foreground and background are assumed to be given.

$$E_p = \frac{M_s^{(F)}}{M_s^{(B)}} \tag{4}$$

Figure 7 shows the correspondence between the predicted value E_p and the subjective evaluation scores. The evaluation scores and the reproduced image magnification ratio E_p show a strong correlation.

In practice, subjective size distortion phenomena such as the puppet theater effect are thought to depend on the foreground and background and on the type of object depicted in the image, and it would be worth verifying these results with many more images. In this report, we have at least shown the geometrical criteria that cause this effect.

3 Depth distortion

Depending on the image shooting and display conditions, the relative size of the reproduced image in the depth direction may become smaller. In such cases, the apparent thickness of the reproduced object is distorted in the depth direction, causing a poor sense of depth. This phenomenon is sometimes called the cardboard effect [1] because it makes three-dimensional objects look like cardboard cut-outs.

3.1 Theoretical analysis

To quantitatively ascertain the thickness of a stereoscopic image based on the camera-to-object distance, we introduced the thickness term E_c expressed by the following formula:

$$E_c = \frac{\left(\frac{dL_d}{dL_b}\right)}{M_s} \tag{5}$$

Here, M_s is the magnification of the reproduced image, and L_b and L_d are the depth distances of the object in real space (where the object image is actually shot) and stereoscopic image display space, respectively. E_c expresses the degree of local changes in the depth direction.

Table 5 shows the results calculated by applying this value to the parameters of parallel and toed-in configurations shown in Table 2.

TABLE 5

Reproduction magnification ratio of depth $E_c = \frac{\left(\frac{dL_d}{dL_b}\right)}{M_s}$					
In the parallel camera configuration	In the toe-in camera configuration				
$E_c = \frac{1}{a_2}$	$E_{c} = \frac{1}{\frac{1}{L_{s}} - \frac{a_{1} \cdot a_{2}}{L_{c}} + \frac{a_{1} \cdot a_{2}}{L_{b}}} \cdot \frac{a_{1}}{L_{b}}$ Especially in the case of $L_{b}=L_{c}$ (when it is reproduced on the screen) $E_{c} = a_{1} \frac{L_{s}}{L_{c}}$				

Analysis of depth distortion

In the parallel configuration, E_c depends on a_2 , which is simply the ratio of the angles of view when the image is shot and when the image is displayed. The situation is more complex in the toed-in configuration, where several factors are involved. However, when considering an object close to the depth position of the display screen, it can be seen that it is related to the camera separation (a_1) , the distance to the intersection of the optical axes when capturing the image (L_c) , and the viewing distance (L_s) . It is suggested that these parameters should be considered in order to avoid the cardboard effect.

3.2 Subjective evaluation tests

The cardboard effect is a phenomenon whereby individual objects in a scene are perceived as having no depth, although it is generally still possible to ascertain the positional relationships among groups of objects in the depth direction. Although an analysis of the occurrence of this phenomenon is inevitably complex, here, we attempt to predict its occurrence in cases where the analysis is restricted to binocular parallax.

In the discussion of the previous section, we showed that the thickness E_c of an object's image is affected by various parameters. When the thickness E_c is small, it is predicted that unnatural phenomena such as the cardboard effect can occur.

We tried to apply the geometrical discussion of the previous section to the results of subjective evaluation tests. In the subjective evaluation tests, stereoscopic images were reproduced under a number of different imaging and display conditions, and the test subjects evaluated the subjective thickness of the object [6].

For the evaluated images, we produced images of the object shown in Fig. 8 under the nine sets of conditions shown in Table 6.

The test subjects were asked to evaluate the subjective thickness of the reproduced stereoscopic image on the following five-grade scale:

- 5: Very thick
- 4: Thick
- 3: Somewhat thick
- 2: Not very thick
- 1: Not at all thick

FIGURE 8

Object used in the subjective evaluation tests of the cardboard effect



TABLE 6

Shooting and display conditions used in subjective evaluation tests of the cardboard effect

condition	1	2	3	4	5	6	7	8	9
camera configuration	toed -in								
the angles of view of lens α (degree)	43.6			13.7			5.7		
shooting distance Lb (m)		3.3			11.0			26.4	
convergence distance (m)		3.3			11.0			26.4	
camera separation dc (mm)	13	39	66	43	130	216	104	311	513
viewing angle ß (degree)					43.6				
viewing distance Ls (m)					3.3				
aı	0.20	0.60	1.02	0.66	2.00	3.32	1.60	4.78	7.89
F.e.	0 20	0 60	1 02	0 20	0 60	1 00	0 20	<mark>0 6</mark> 0	0 99

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Figure 9 shows the correspondence between the thickness E_c and the subjective evaluation scores. The vertical axis shows the results of normalizing the 5 evaluation categories in psychological space by using the method of successive categories. The calculation and subjective evaluations are clearly correlated.

The cardboard effect is a subjective effect that might be affected by other cues such as motion parallax and shading information. In this Report, we have at least shown the geometrical criteria that cause this effect.

FIGURE 9 Correspondence with subjective evaluation scores



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Annex 2 to Attachment to Annex 4

Parallax distribution and visual comfort of stereoscopic images

1 Introduction

One of the issues that arises when making stereoscopic images widely available to large numbers of viewers is the visual discomfort experienced by viewers of some scenes. This discomfort is thought to be caused by discrepancies and crosstalk between the characteristics of the images presented to the left and right eyes, such as differences in their geometrical characteristics or video properties, and is thought to be more of a problem in scenes where these characteristics are prominent. Another factor is parallax itself, which plays a key role in conveying the sense of depth.

It has often been noted that excessive parallax can cause visual fatigue. There are many productions where surprisingly large amounts of parallax are used intentionally for dramatic impact. If we can find out about the distribution of parallax within the same frame and how this distribution affects the viewer's visual discomfort, then this should provide us with very useful clues for the production of visually comfortable stereoscopic images in each scene. It can sometimes be difficult to analyse the parallax values included in a frame. In what follows, we describe such an analysis and apply it to a number of stereoscopic images. We then compare its results with those of subjective evaluation tests.

2 Parallax measurements

Here we summarize the parallax measurement method used in this study.

For many applications, we ideally need to be able to determine the depth (i.e. the amount of parallax) for each pixel of an image. However, algorithms for analysing parallax are generally prone to errors. Also, in practice there are cases where corresponding pixels do not exist in the images presented to the left and right eyes due to occlusion. In this study, we do not need to measure parallax on a strict per-pixel basis as long as we are able to extract the characteristics of a parallax distribution from the images. To achieve this aim, the method we propose combines phase correlation with a number of threshold processing methods. A detailed description of this algorithm can be found in Reference [1]. The algorithm was used in the parallax analysis of stereoscopic images discussed below.

3 Subjective evaluation tests of parallax distributions and visual comfort

We performed subjective evaluation tests to investigate the relationship between visual comfort of stereoscopic images and their parallax distributions [1]. The subjective evaluation test conditions are shown in Table 7. The images used for the evaluation consisted of 48 different still images. These images were presented as stereoscopic images with 2D images as a standard reference, and their relative visual comfort was evaluated on a seven-grade scale. The 2D images were produced by presenting the left-eye image to both eyes and were evaluated by test subjects wearing the same polarizing glasses used for the stereoscopic images. The parallax in the stereoscopic images was measured by using the phase correlation method discussed in § 2. Here, the amount of parallax was measured on a per-pixel basis with the screen corresponding to a value of zero, and positions behind and in front of the screen correspond to positive and negative parallax values respectively. In the viewing conditions shown in Table 7, the amount of parallax of a single pixel corresponds to a separation of approximately 1 mm between the left and right images on the screen. Figure 10 shows

the results of the visual comfort subjective evaluation tests and the results of measuring the amount of parallax in the images. In the graphs of this figure, the numbers on the horizontal axis designate the images to be evaluated. The graph at the top shows the results of the subjective evaluation tests. The vertical axis shows the mean value of the evaluation scores from 24 evaluators, and the vertical bars represent the standard deviations of these scores. The lower graph shows the results of measuring the amount of parallax. The vertical axis shows the amount of parallax measured in pixel units, the plotted points show the average values of the parallax in the images, and the vertical bars show the range of the parallax distributions. The upper and lower ends of the vertical bars represent the maximum and minimum parallax values. A comparison of the two graphs shows that the images with an evaluation score of 3 or less have a very large parallax distribution range.

TABLE 7

Images used in test48 still images (including a standard pattern)					
Subject	24 adult males and females (not expert)				
Repeat test	10 s viewing of 2D image (for reference), following by 10 s viewing of stereoscopic image (for evaluation)				
Display system	Stereoscopic HDTV using polarizing glasses				
Screen size	90 inches				
Viewing distance	About 3H (3.33 m)				
Peak brightness	15 cd/m ²				
Method of evaluation	Relative evaluation on a scale of seven, based on 2D image				

Conditions of subjective evaluation tests of parallax distributions



FIGURE 10 Evaluation test results and parallax measurement results

On analysing the correlation between the results of the subjective evaluation tests relating to visual comfort and the statistical quantities (mean, range, minimum, maximum, variance) of the parallax distributions, it can be seen that the parallax range exhibits a strong correlation with a correlation coefficient of -0.86 (99% confidence).

Figure 11 shows the relationship between the parallax distributions and visual comfort of the images used in the evaluation. The vertical axis shows the amount of parallax in pixel units with a value of zero corresponding to the position of the screen, and the horizontal axis shows the visual comfort derived by using the method of successive categories to combine the psychometric values. The plotted points represent the mean values of the parallax distributions in the images, and the vertical bars represent the range of the parallax distributions. From Fig. 11, we can see that in each image evaluated as being visually comfortable, the range of the parallax distribution is approximately 60 pixels or less. This translates to a value of 0.3 diopters. Images are evaluated as being comfortable when the parallax distributions are in the range from approximately 30 pixels in front of the screen to approximately 65 pixels behind it.

Next, we investigated the relationship between the average values of the parallax distributions and the visual comfort of the images. With seven of the images, we performed visual comfort evaluation tests in which the average value of the parallax distribution was shifted to different positions. These tests were performed with 20 test subjects. The other test conditions were the same as in Table 7. Figure 12 shows the experimental results. In this figure, the points plotted with outlined symbols represent data obtained without horizontal shifting. As Fig. 12 shows, as the average value of the parallax distribution became closer to the screen position, the images were evaluated as being more visually comfortable.



FIGURE 11 Parallax distribution vs. visual comfort

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4 Subjective evaluation of the sense of presence

When scenes are limited to small values of parallax there might be a reduction in the positive effects of the stereoscopic images, such as the sense of presence. In the tests reported in § 3, the images were evaluated in terms of their sense of presence as well as their visual comfort. Specifically, the stereoscopic images were presented with 2D images as a standard reference, and their sense of presence was evaluated on a seven-grade scale.

In the analysis of the test results, we found no significant correlation between the sense of presence scores and the statistical quantities of the parallax distributions. We extracted the images for which the stereoscopic image was evaluated as more visually comfortable than the 2D image (35 images in total), and as a result of analysing these images, we showed that there is a strong correlation between the range of the parallax distribution and the sense of presence (correlation coefficient 0.65).

On the other hand, we observed no factorial effect of the average value of the parallax distribution on the sense of presence evaluation scores.

References

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Annex 5

Italian Health Ministry Circular Letters

The Italian Health Ministry issued a Circular Letter dated March 17, 2010, addressed to all the Regional Health Agencies, the Police, the associations of cinema operators and for information to the Ministry for Economy Development, which is responsible for telecommunications including broadcasting. The Italian Ministry action was prompted by a request of the Italian Consumer Protection Authority, and it was based on advice provided by the Ministry's High Advisory Council on Health. Some further clarifications were issued in a subsequent circular letter dated 6 August 2010.

The circulars are available (in Italian) on the website of the Ministry, and a translation is provided below.

The Ministry circular letter of March 17, 2010 states that:

- the scientific literature does not seem to provide firm proof that viewing stereoscopic programming would force human eyes and brain to perform unnatural processing of visual information; consequently there are no clinical indications at this moment against the use of 3D spectacles during cinema screenings, on condition that such screenings are limited in duration (the advice of the High Advisory Council on Health on this point was more detailed: it is suggested that viewing should be limited in time, and that it should contain intermissions proportionate to the total programme duration);
- some functional problems may arise in young viewers due to the use of 3D spectacles to view cinema presentations, because binocular vision may not yet be present or well established in young viewers, or because they may be cross-eyed or amblyopic, or because they may be going through a period of *visus* rehabilitation; however those problems should cause no irreversible damage or pathologies;
- consequently, the public that attends stereoscopic screenings should be informed that children under six years should not use 3D spectacles and that even adults should not use them for a duration that exceeds a single screening session.

A further circular letter of the Ministry, dated 6 August 2010, stated that in those cases when singleuse glasses cannot be considered due to their technology or cost, 3D glasses must be properly disinfected and repackaged before they are provided to the next user since the risk of transmission of bacterial infections tends to increase with the successive use of the same spectacles by different viewers.

Annex 6

A preliminary set of possible performance requirements for a 3DTV broadcasting service

This Annex is a collation of candidate performance requirements for a 3DTV broadcasting service that have been identified in contributions submitted to WP 6C since October 2008. As far as possible, each is presented in the form in which it appeared in the original contribution, and the source contribution is indicated. They are listed in order of the contributions in which they are mentioned.

It should not be assumed that this list is comprehensive, or that each would necessarily be applicable to all possible types of 3DTV services.

- a) The goal of the 3DTV viewing experience should be to create the illusion of a real environment, which can be watched for an indefinite period of time by an audience with normal visual acuity (Document 6C/128).
- b) The quality of the 3DTV service should be established by two principal parameters: sensation of reality and comfortableness or ease of viewing (Document 6C/128).
- c) In the case of a 3DTV emission system that is intended to allow for the compatible reception of conventional SDTV, EDTV or HDTV digital signals, no perceptible degradation of the conventional television presentation should be caused by the additional signal coding required to convey the extra information needed for 3DTV (Document 6C/128).
- d) The viewing experience provided by a new 3DTV service should represent a major improvement as compared to the experience provided by HDTV broadcasting at its best quality level (Document 6C/155).
- e) A new 3DTV service should be implemented in a way to match the viewing habits that will likely be typical of television audiences at the time when the service will be introduced (Document 6C/155).
- f) A single set of image and sound specifications should be recommended for the new 3DTV service, unless it is essential to choose more than one set of specifications in order to reflect unavoidable regional constraints (Document 6C/298).
- g) It would be desirable, albeit not imperative, to preserve a certain degree of backward compatibility of the new 3DTV service with existing consumer receivers (Document 6C/298).
- h) The image and sound system parameters of each new television broadcasting application should be optimized on the basis of the performance requirements specific to the 3DTV service, even if this requires departing from technical solutions adopted for other applications (Document 6C/298).
- j) Specifications should be recommended for a new 3DTV broadcasting service after it has been demonstrated through life-size simulations and tests that it offers new attractive features, and that broadcasting audiences that have been exposed to it, have appreciated its features and have expressed their interest to gain access to it, purchasing the necessary consumer equipment (Document 6C/298).
- k) The issue of visual fatigue and other possible health hazards related to extended viewing of 3DTV programs based on presentation methods currently available or proposed, should be resolved prior to developing Recommendations on technical specifications for a future 3DTV broadcasting service (Document 6C/299).