# REPORT ITU-R BT.2088

## Stereoscopic television

(2006)

## 1 Introduction

Stereoscopic image systems allow the illusion of depth to be presented using a flat display. They have been developed for cinema, television and other uses such as medical imaging. Stereoscopic image systems should not be confused with holography, which requires the use of lasers and is not in general compatible with existing cinema or television technology.

The technology for stereoscopic still imaging has existed almost since the invention of photography in the mid 19th century. For moving images, it has existed commercially since the 1950s.

ITU-R documents on stereoscopic television currently include one active Question and a further question in the approval process, two Reports and two Recommendations:

Question ITU-R 88/6 – Subjective assessment of stereoscopic television pictures.

Report ITU-R BT.312 – Constitution of a system of stereoscopic television (last updated 1990). This Report briefly describes techniques for reproducing stereoscopic images, lists requirements for development of practical stereoscopic television systems, lists prior CCIR documents on the subject and has a short bibliography.

Report ITU-R BT.2017 – Stereoscopic television MPEG-2 multi-view profile.

This Report describes Amendment 3 to the MPEG-2 video coding standard (ITU-T Recommendation H.262/ISO/IEC 13818-2), ratified in 1996, which allows for coding of stereoscopic images.

Recommendation ITU-R BT.1198 – Stereoscopic television based on R- and L-eye two channel signals (1995).

This provides a brief (one page) list of requirements for compatibility between monoscopic and stereoscopic signals for broadcast, and specifically mentions autostereoscopic displays in the considerations.

Recommendation ITU-R BT.1438 – Subjective assessment of stereoscopic television pictures (from Question ITU-R 88/6 Subjective assessment of stereoscopic television pictures, formerly Question ITU-R 234/11).

This covers: assessment factors, assessment methods, viewing conditions, visual screening of observers and test materials, both still and moving.

It is timely to review the subject of stereoscopic imaging for several reasons:

– Developments in broadcast image technology have brought larger, flatter screens at increasingly affordable prices. These offer an ideal platform for various implementations of stereoscopic images.
– Personal computer technology has encouraged the development of LCD shutter spectacles for computer games. These are now affordable and readily available.

– The advent of digital broadcasting has brought greater flexibility in image encoding formats. This flexibility offers the possibility of stereoscopic imaging with much improved monoscopic compatibility. By contrast, stereoscopic images encoded using analogue techniques generally showed visible artefacts such as ghosting, flicker or "puppet-theatre effect", and had limited monoscopic compatibility.
– Developments in computer-generated imaging now allow highly detailed synthetic stereoscopic images to be generated almost as easily as monoscopic images.

## 2 Stereoscopic vision and parallax

Stereoscopic image systems use two images, one presented for each eye. For correct parallax, these images should be captured from positions about one inter-ocular distance apart (about 65 mm). The difference in perspective from the two positions allows depth to be perceived when the brain compares the two images presented separately to the right and left eye.

The close spacing of the image capture points places some constraints on cameras and lenses. In some cases, this restricts permissible combinations of aperture and focal length. The use of mirrors however can alleviate such problems to some extent. It is not currently possible however to post-process stereoscopic images to change their parallax. This places a responsibility on both the camera designer and the camera operator to consider parallax effects at all times.

Parallax is often varied in 3D production work for creative effects. Conventional parallax will cause the stereoscopic image to appear behind the screen. Parallax can be reversed however by swapping left and right images to make the image appear in front of the screen, with resulting image distortions. Parallax may also be exaggerated by varying the inter-lens distance to enhance or reduce the apparent depth.

Parallax is a particular problem for macro close-up images as the focal length may be comparable to, or shorter than, the inter-ocular distance. This can lead to unpleasant effects due to a short depth of field and/or lack of overlap between the left-eye image and the right-eye image and/or large angles subtended by the viewed object and the image capture points. To solve this problem, parallax may be deliberately distorted in macro work by reducing the inter-lens distance on the camera. The optical paths may also be skewed to increase image overlap. This technique is commonly used in stereo microscopy. As parallax gives not only depth information but also information about scale, a side-effect of this parallax distortion is that the image is given an unrealistic scale, appearing much larger than its actual size. While this gives some scope for creative effects, the brain is able to compensate because it knows that it is using an artificial viewing system.

## 3 Compatibility – general

Just as it is desirable for colour video to be compatible with monochrome video, it is desirable for stereoscopic video to be compatible with conventional monoscopic video. Most early stereoscopic video systems were not very compatible with conventional video, resulting in blurry and/or flickering images when viewed on a normal monitor. This issue is discussed in more detail for each individual stereoscopic technique.

## 4 Display techniques and technologies

Stereoscopic image technology has existed for well over a century, originating with the work of Wheatstone and Brewster on static imaging in the 1830s. Because the main technologies for stereoscopic moving images involved image separation by colour, stereoscopic motion picture technology was not developed until after WWII when the use of colour film stock became widespread.

A number of systems have been used commercially for viewing stereoscopic moving images. Most of these systems, with the notable exceptions of time multiplexing and Pulfrich effect, are developed from still-image stereoscopic photography techniques. These techniques include chromatic anaglyph, polarization anaglyph, and integrated anaglyph.

## 4.1 Discrete image displays

### 4.1.1 Head-worn displays

Left-eye and right-eye images can be presented using discrete displays worn as spectacles. These were used in some early "virtual reality" video games. These displays and their images move with the head however, which can be disconcerting, and because of the small display size, the resolution is limited. The technique is not really suited to viewing by groups.

### 4.1.2 Side-by-side displays with prismatic spectacles

Discrete displays can also be used at a distance provided the optical paths to the eyes are suitably bent either by spectacles containing mirrors or prisms. This technique requires the viewer to minimize head movement and can be quite fatiguing.

## 4.2 Anaglyphic display

Anaglyphic displays superimpose two images in the same display and then separate them for viewing by optical filtering.

### 4.2.1 Separation by colour filter (chromatic anaglyph)

Any combination of mutually exclusive colours can be used for the chromatic anaglyph display. For full-colour rendition of the neurally-recombined image, complementary left eye/right eye colours should be used – red/cyan, green/magenta or blue/yellow. The convention is to use red and cyan, as this combination has a simple low-pass/high-pass wavelength characteristic. While green/magenta has a better match of luminance values (see Table 1), this combination requires a band-stop/band-pass characteristic which is more difficult to reproduce accurately and consistently.

TABLE 1

**Luminance values and luminance ratios of complementary colours used for anaglyphic representation (using PAL/SECAM/NTSC/SDTV colorimetry)**

| Colour 1 | Colour 2 | Luminance ratio |
|---|---|---|
| Red | Cyan | |
| Y' = 0.299 | Y' = 0.701 | 2.34 |
| Green | Magenta | |
| Y' = 0.587 | Y' = 0.413 | 1.42 |
| Blue | Yellow | |
| Y' = 0.114 | Y' = 0.886 | 7.77 |

The coloured filters are used at the image capture stage by two separate cameras. The two images are then mixed and presented as a single image for viewing. The two parts of the image are then separated into left-eye and right-eye images by spectacles with red/cyan lenses. The combined transmission spectrum from these two filters approximates white light. This is the cheapest and oldest stereoscopic technology for moving images and a considerable catalogue of material exists in this format. This system is implemented easily in both cinema and television, although the realism of the image is impaired by the incomplete colour information received by each eye. In effect, each eye is operating with partial colourblindness with this system. On the plus side, this system requires only a single cinema projector or television display and the image separation for the viewer is passive and therefore requires no power, circuitry, synchronization or distribution.

#### 4.2.2 Polarization anaglyph or vectorgraph

This process is similar to the colour filter process but instead relies on polarization of the light at +45° for the right eye and –45° for the left eye for image separation. This system was patented for still projection before 1900 [McKay, 1953], was pioneered in cinema in the 1950s by Arch Oboler and was used until 1990 in IMAX cinemas. It provides superior realism compared with the colour-filter system as each eye in the polarized system receives a full-spectrum image. It was never widely adopted however because it needed specialized projectors, making it uneconomic for many smaller cinemas. It has the advantage however of still being a passive system, requiring only polarized spectacles for the viewer. It is however a difficult technique to implement in a television system.

#### 4.2.3 Lenticular/integrated anaglyph (autostereoscopic)

The lenticular anaglyph system uses two images displayed simultaneously in interleaved vertical strips. A cylindrical lenticular lens system on the screen then focuses the two images separately about one inter-ocular distance apart. The system relies on careful head positioning to achieve the stereoscopic effect. This system needs no viewing spectacles and is therefore known as an autostereoscopic system.

### 4.3 Pulfrich effect

This system uses spectacles/goggles with one tinted lens (left eye) and one untinted lens (right eye) and is based on the longer transmission time for the brain to receive the dark image. The effect is mainly observed on images moving horizontally, from left to right using the arrangement described. The system has the advantage of compatibility with monochrome displays but has the disadvantage of requiring horizontal motion in the image to create the depth effect. No commercial implementation of this system is known.

### 4.4 Time-domain multiplexing

This process sends left-eye and right-eye images sequentially. The images are then separated for the viewer by active spectacles with alternating synchronized shutters, usually using LCDs. This system has been used in IMAX cinemas since 1990, is used in computer games and can be used for television. The images produced by this technique can suffer from flicker however due to the low refresh rate (12 images/s for standard cinema, 12.5-15 images/s for interlaced television). The technique works much better at the higher refresh rates used with progressive scanning.

## 5 Digital stereoscopic image encoding and monoscopic compatibility

The encoding of a different image in each field of an interlaced image or in each frame of a progressive-scan image poses data reduction problems for digital encoding systems. As there can be significant difference between the left-eye image and the right-eye image, particularly for close-up shots, the amount of data reduction available by encoding the difference between images is significantly reduced. It is possible however to reconfigure these systems for greater efficiency by splitting the signal into two separate sub-streams (left-eye and right-eye). This configuration has been added to the MPEG-2 video encoding standard and is described in Report ITU-R BT.2017.

## 6 Stereoscopic production formats

While stereoscopic presentation requires a dedicated display, and usually, some form of optical multiplexing and demultiplexing, stereoscopic production does not inherently require such multiplexing. All that is necessary is to capture two simultaneous image streams with the correct separation distance. It is then quite feasible to produce and post-produce this material in discrete form, only combining and encoding the material for the required reproduction format at the presentation stage. While discrete dual-image production may require more equipment, or more elaborate equipment, than anaglyphic image recording, it is inherently more flexible and can be used for multiple reproduction formats if required. If no standard reproduction format is chosen for stereoscopic television, it will be essential to maintain discrete two-image production practices. Fortunately, the MPEG-2 MVP extension (see Report ITU-R BT.2017) allows the signal to be encoded in this way. Equivalent production formats will be needed also. If these are to be accommodated within the bandwidth of existing equipment, some image quality loss may have to be tolerated.

## 7 Conclusion

When implemented well, the enhanced image rendition of stereoscopy gives a greater sense of involvement, greater realism and potentially, a more satisfying experience to the audience. In this regard it has much in common with surround sound technology, which has enhanced the audience experience in both cinema and television.

Recent technological developments, particularly in displays and digital encoding, have brought the practical, wide-scale implementation of stereoscopic television much closer. In this regard also, stereoscopic imaging has much in common with surround sound, which has been widely adopted since the introduction of digital broadcasting.

In terms of image technology, stereoscopy presents the next major challenge to researchers, developers, manufacturers and broadcasters now that monoscopic digital television broadcasting is firmly established. There is still much work to be done in standardizing and refining both production formats and delivery formats for this new medium.

Specifically, the areas currently needing work in the ITU-R are:

– determining whether a common stereoscopic display format is necessary or desirable and if so, defining quantitative and qualitative performance criteria for its evaluation and selection;
– establishing common stereoscopic production formats for easy program exchange and distribution;
– specifying desirable features and performance standards for stereoscopic production equipment;
– defining recommended stereoscopic production practices;
– defining stereoscopic quality standards and quality control procedures;
– determining whether stereoscopic television emission systems will be any more susceptible than monoscopic emission systems to signal strength effects, interference effects, topographic effects or other emission-related factors which may affect overall system performance.

## 8 References and bibliography

There is a considerable body of literature on this subject. The references and bibliography below are far from exhaustive, but should provide a starting point for those wishing to learn more.

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