

Evaluation of a Single User autostereoscopic Display System for 3D-TV and PC oriented applications - an example of a user centered design cycle

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Abstract

We report outcomes of a human factors experiment dedicated to test a prototype single user autostereoscopic (glasses-free) display designed for 3D-TV, internet browsing, and future communication applications. This display is based on a special head-tracking lenticular-screen 3D display principle in order to provide good image quality and free positioning of the viewer. Main objective of the reported study was to identify potential technical shortcomings of the set-up in order to improve critical system parameters in the final version. Ten display experts participated in the experiment. Each subject completed 36 experimental trials. They rated 3D image materials under different viewing conditions in terms of image quality, depth impression, image artefacts, impairment and viewing comfort. Overall, our results show good image quality and depth impression ratings across the tested viewing conditions, especially in a fixed observer position. As soon as the observer moves the assessed variables slightly decrease. Concerning the viewing area our findings indicate to enhance tracking accuracy not only in the centre of viewing zone but also at the border areas in order to improve the viewers feeling of unrestricted positioning.

Key words: Autostereoscopic display technology, viewer tracking, depth impression, image quality, visual comfort

1. Introduction

The ATTEST 3D-TV broadcast chain

At HHI an autostereoscopic single user display has been developed. The R&D work is part of the *ATTEST* project (Advanced Three-Dimensional Television System Technologies), funded by the European Information Society Technologies (IST) 5th framework program. Main aim of *ATTEST* is to design a flexible, 2D compatible and commercially feasible end-to-end 3D-TV broadcast chain. The project comprises 3D content generation, 3D coding and autostereoscopic display technology. Research into human perception and usability requirements play a central role throughout the project. Results of formative user centered evaluations support the design process such that further refinements can be incorporated in the final *ATTEST* prototype.

The scope of application areas of the autostereoscopic display technology under development is not only limited to the entertainment section such as 3D-TV –the target application in

ATTEST— but also extendable to PC-oriented multimedia applications and video communications.

Principle of stereoscopic and autostereoscopic displays

The human eyes perceive a real-world scene from slightly different perspectives. Binocular depth perception is largely based on the evaluation of these differences. Accordingly, 3D displays create the 3D effect by redirecting two slightly different images to the right and left eye. In the case of traditional stereoscopic display techniques viewers wear special viewing aids such as anaglyphic, shutter or polarization glasses in order to direct the separated left and right view to the appropriate eye. An important issue and challenge for display designers is to separate the left and right eye view correctly. If both channels are not separated perfectly this may lead to crosstalk, perceived as ghosting (double images) and makes stereoscopic images strenuous to watch.

To overcome the constraint of wearing glasses, in autostereoscopic displays the eye-addressing techniques are completely integrated in the display itself (Pastoor and Wöpking, 1997).

In general, existing autostereoscopic displays allow only a fixed viewing position in order to channel the left and right eye view in the appropriate eye of the observer. Some others include a limited form of head tracking providing a multitude of fixed positions. Within *ATTEST* a non-intrusive video based head tracking has been developed that allows viewers to move freely in all directions (x – lateral, y – up and down, z – back and forth). Technical details of the set-up are described in the next paragraph.

Technical description of the ATTEST Single User Display

For the representation of stereoscopic content, a left eye view and a right eye view must be presented at virtually the same time. The *ATTEST* single user display consists of a 20 inch flat LC display equipped with a lenticular lens plate to separate the two views, which is mechanically adjusted according to the viewer's position. That is: For the image separation left and right images are split into vertical stripes which are steered on the appropriate eye by means of cylindrical lenses. Depending on the viewers positioning, this lens plate is tracked in two axes with high precision. The detailed technical design of the 3D display is shown in figure 1.

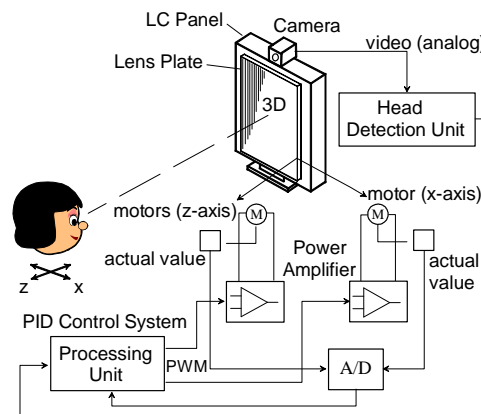


Figure 1: Technical design of the test set-up

The Tracking System and Viewing Zone

As can be seen in figure 1, a camera based head detection device was developed to sense the 3D head position without any user worn devices. In order to detect the eyes of a potential observer the pattern of the captured images are analyzed via a PC based frame grabber system. The processed head location data are sent to a processing unit which supplies a pulse-width modulated data stream for driving several motors. The required real time performance and precision for a spatial positioning of the lens plate is achieved by means of a custom-made PID control system.

Figure 2 shows the tracked viewing area in front of the display. The area corresponds to the field that allows correct reproduction of stereoscopic images. The proportions were tested in a pilot test. Up-and-down movements do not require opto-mechanical adjustments since there is no direction selectivity of the cylindrical lenslets in the vertical direction.

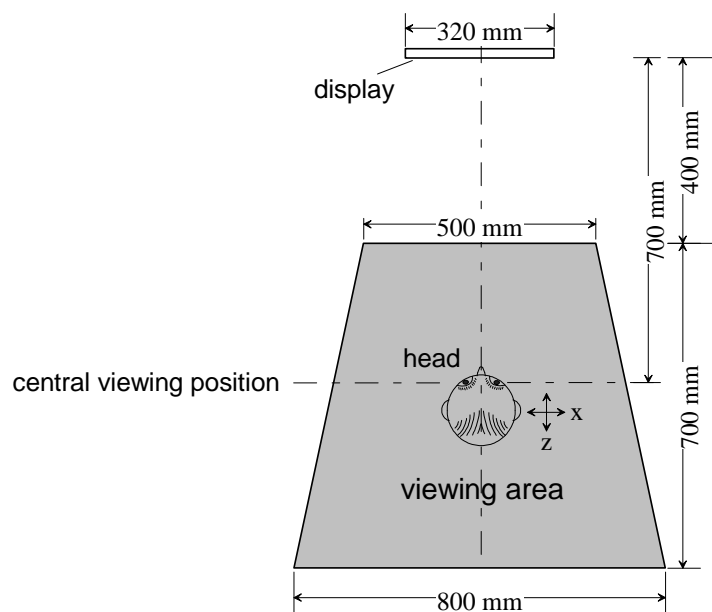


Figure 2: Viewing area

Aim of the human factors experiment

Aim of the subjective evaluation was to test the single user display quality and head tracking accuracy under critical viewing conditions. Aspect of particular interest was real time tracking behaviour in terms of precision, tracking range and robustness. Open questions were related to whether the tracking system would be fast enough and how it would react to different observer movements. Furthermore, we were interested in user reactions towards the limitations of the viewing zone. The tracked area should allow sufficient possibilities of observer movements in order to provide a comfortable viewing experience and a distortion-free depth impression.

2. Method

Stimulus material

The test materials being applied in the experiment included stereoscopic still images as well as moving stereoscopic images (produced by NHK, Japan for research purposes on stereo

video). These materials were selected with respect to particular image properties such as binocular disparity values or background attributes.

Figure 3 shows the stereoscopic still images. All stills (one photo and two synthetic images) were colored images with a size of 320x399mm in portrait format and a spatial resolution of (2x512)x1280 pixels. This resulted in a spatial resolution of 512x1280 pixels per view.

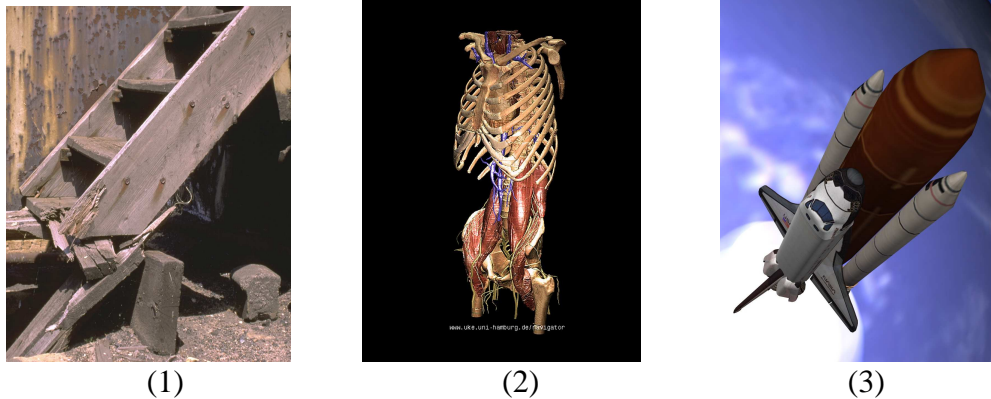


Figure 3: Stereoscopic still images: 1. Ladder, 2. Anatomy, 3. Shuttle

Figure 4 shows images of the video sequences. The stereoscopic video sequences were captured with standard TV cameras. Post processing of the image material improved the image quality and adapted the format of the sequences to suit the display in a size of 320x213 mm. Each video sequence took 15 seconds. The source materials were in the ITU-Rec. 601 format (International Telecommunication Union), with a spatial resolution of 702x480, 60 Hz interlaced (ITU, 1994).

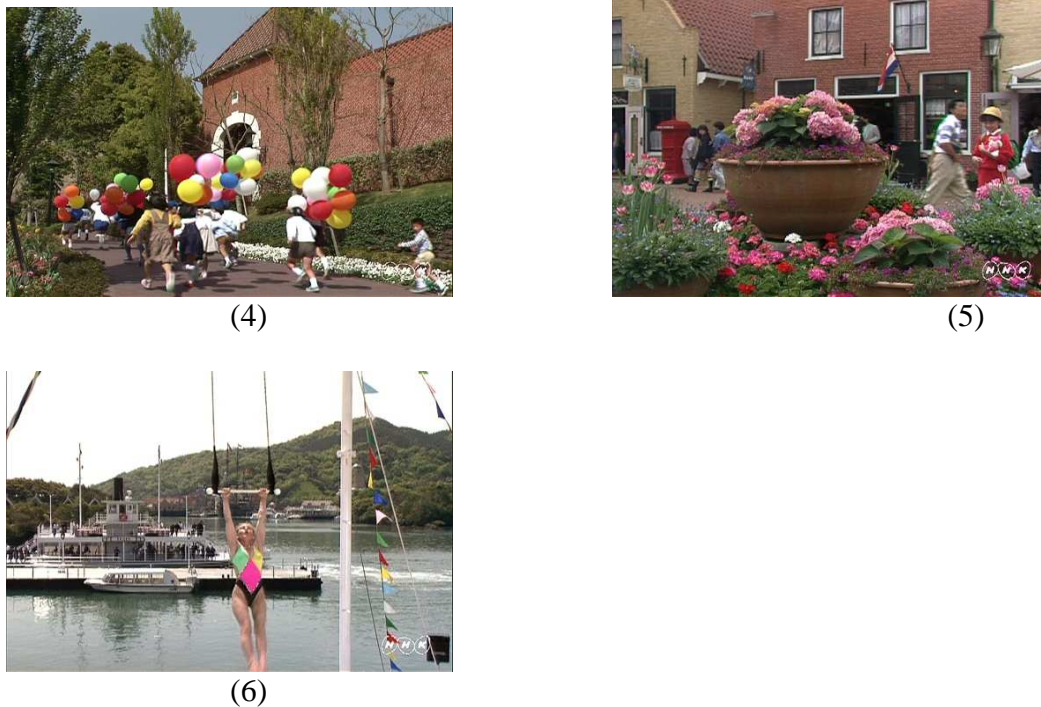


Figure 4 : Example frames of the stereoscopic video sequences: 4. Balloons, 5. Flower Pot, 6. Trapeze

The Experimental Design

The experimental design comprises two factors: *image content* (three stills and three video sequences) and *observer movements* (six distinct head and body movements defined in a pilot test) resulting in 36 sub trials as shown in Table 1. Viewers explored the different stimulus materials while performing different head and body movements in front of the display (see Table 1). The tracking area was highlighted by red bands. The general viewing conditions were set according to ITU-R BT. 500-10 (ITU 2000).

Image content: 3D still images		Ladder	Anatomy	Shuttle
	1. Fixed position	A1	A2	A3
	2. upper body slow (x)	A4	A5	A6
	3. upper body faster (x)	A7	A8	A9
	4. upper body back and forth (z)	A10	A11	A12
	5. Head rotation slow	A13	A14	A15
	6. Head rotation faster	A16	A17	A18
Image content: 3D video sequences		Balloons	Flower Pot	Trapeze
	1. Fixed position	B1	B7	B13
	2. upper body slow (x)	B2	B8	B14
	3. upper body faster (x)	B3	B9	B15
	4. upper body back and forth (z)	B4	B10	B16
	5. Head rotation slow	B5	B11	B17
	6. Head rotation faster	B6	B12	B18

Table 1: The experimental conditions: A1-A18 for still images, B1-B18 for video sequences

Assessment procedure

The single stimulus subjective test method according to ITU-Rec. 500-10 was applied (ITU, 2000). One test stimulus was presented per trial. Subjects explored the images as long as they wanted before they gave their judgement. They were asked to rate each stimulus with respect to image quality on a continuous quality scale ranging from bad to excellent at the end of each trial. The labels “Excellent”, “Good”, “Fair”, “Poor”, “Bad” were printed alongside the scale. The same rating scale was used to measure depth impression and viewing comfort. Moreover, subjects were asked to describe the perceived image degradations and subsequently rated the perceived overall impairment on an impairment scale ranging from very annoying to imperceptible.

Each participant completed 36 experimental trials (see Table 1). The entire session lasted 90 minutes, on average. Two practice trials were conducted prior to the main test, in order to familiarise the subjects to the task and the test material.

After the main experiment, subjects answered several questions concerning the viewing zone and personal data.

Subjects

Ten display experts participated in the experiment, all were male and in the age from 28 to 55 years. They had normal or corrected to normal vision (six subjects wore glasses). Seven subjects had prior experience in performing perception experiments such as this display evaluation. Concerning the display experts' knowledge, six subjects indicated to be highly

experienced in display technology and four subjects stated to have moderate or little experience.

3. Results

The assessment includes descriptive statistical analyses, a qualitative analysis of the written descriptions of image impairments and a summary of observations and comments.

Overall image quality ratings

For the stereoscopic still images the subjective ratings indicate a decrease of perceived image quality if the observer moves. In a fixed viewing position, the perceived image quality is on average between good and excellent. The average image quality is rated between fair and good if the observers move in the x- and z-direction, whereas the same stereoscopic images are assessed between poor and fair if the observers rotate their head. Figure 5 shows a histogram of image quality results across the six viewing conditions.

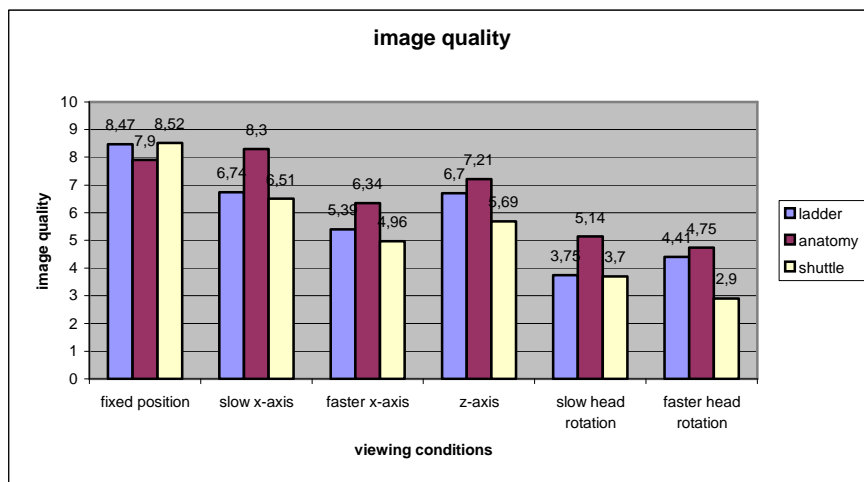


Figure 5: image quality of stereoscopic static images across viewing conditions

As can be seen in figure 6, the image quality ratings vary less for stereoscopic sequences. The image quality ratings are on average between fair and good for a fixed viewing position, movements in x- and z- direction and head rotation.

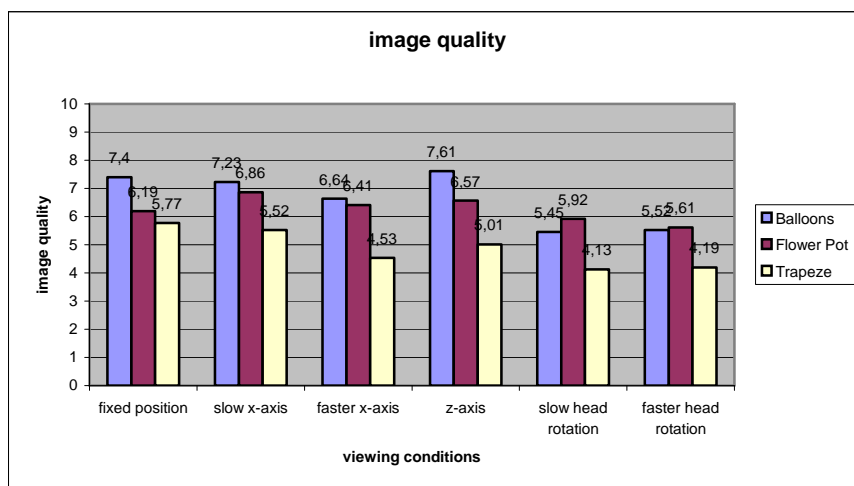


Figure 6: Image quality of stereoscopic sequences across viewing conditions

Except from the observer movements, the perceived image quality seems to depend on shooting conditions and scene content. The perceived image quality decreases if the stereoscopic image material contains excessive disparity values (*shuttle*), or if a stereoscopic video sequence consists of scene transitions with large varying disparity values (*trapeze*). On the other hand, observer movements may have less effect on the perceived overall image quality if image distortions are masked due to the scene content, e.g. a dark background (*anatomy*).

Depth impression ratings

The depth impression seems to suffer most from head rotations while viewing stereoscopic still images. The tracking system seems to lose track of the viewers eyes, because the interocular distance changes when rotating the head and consequently, the two stereo views can't be displayed correctly in the right and left eye. In this case the depth impression is, on average, rated between poor and fair. The depth impression is between fair and excellent while viewing the still images in a fixed position or moving in x- and z- direction. While viewing stereoscopic sequences all observer movements resulted in a depth impression between fair and excellent.

Viewing comfort ratings

Stereoscopic still images with moderate disparity values (*ladder, anatomy*) are, on average, rated between fair and excellent. The viewing comfort decreases if the static image contains excessive disparity values (*shuttle*). In this case, for all observer movements the viewing comfort is, on average, rated between poor and fair.

The viewing comfort experienced with stereoscopic sequences is rated between fair and excellent, for all observer movements. Although the effect is less apparent in comparison to the still images, a sequence containing excessive disparity values (*trapeze*) seems less comfortable to view than sequences with moderate disparity values (*balloons, flower pot*).

Overall, observer movements seem to affect the visual comfort ratings less than the shooting conditions and/or scene content.

Descriptions of perceived image impairments

The written descriptions, observations and comments of the participants gave important details in order to facilitate the further development of the tracking system. No severe image distortions are reported in a *fixed position*. A *slow upper body movement* of the viewer leads to crosstalk, perceptible as shadows or dark stripes, and flicker, particularly visible at border areas. The impairments increase when viewers perform a comparatively *faster body movement*. *Movements back and forth the z-axis* show that the tracking system operates partly incorrect. Subjects report 3D breakdowns while moving forward. According to observations of the participants, the back and forth motion seems to be not as impairment sensitive as the parallel motion along the x- axis, even though flicker, and black stripes are perceptible, mainly at the border of the screen. *Slow and faster head rotations* lead to stronger image impairments. The depth impression breaks down, crosstalk becomes visible as black stripes and shadows. All impairments are experienced as unpleasant and strenuous for the eyes. Additionally, acoustical noise caused by the driving system of the lens plate is mentioned across all dynamical viewing conditions and is experienced as an impairment of the visual sensation.

Overall impairment ratings

The overall impairment ratings reflect, how annoying the reported artifacts were judged by the participants. The degree of annoyance of perceived impairments depends on the body movements and the scene content. In a fixed position the stereoscopic still images were judged, on average, between slightly annoying and perceptible but not annoying. Body movements in the x- and z-direction as well as head rotations result in average impairment ratings between annoying and slightly annoying. The impairment ratings for stereoscopic sequences were slightly different. Observers seem to be less sensitive to impairments in stereoscopic sequences while moving in the x- or z- direction. In this case the observers judge the overall image impairment similar as in a fixed position, which is, on average, between slightly annoying and perceptible but not annoying.

The impairment ratings of stereoscopic static images and sequences are also affected by shooting conditions and scene content. Again excessive disparity values decrease the impairment ratings and observer movements seem to have less effect on the impairment judgments if impairments are masked due to the scene content (anatomy).

4. Conclusions

The findings have the following practical implications for the further development of the tracking system:

The subjective results indicate that especially fast lateral observer movements in front of the display (x-direction) and head rotations can lead to annoying artifacts. The viewing experience can be significantly enhanced by increasing the tracking speed, and improving the tracking accuracy such that the system can keep track of head rotations, faster observer movements in the x- and z-direction and observer movements at the borders of the viewing area. Furthermore, the test showed that acoustical noise produced by the tracking system should be reduced. This may increase viewing pleasure.

Some technical solutions overcoming these deficiencies have already been incorporated in a follow-up display version. Especially the real-time performance and the tracking accuracy have been improved. A revised tracking electronic avoids the occurrence of disturbing acoustical noise.

Moreover, our experimental results show that excessive disparity values should be avoided. Otherwise observers may experience visual discomfort or difficulties to fuse the left and right-eye image. In addition, scene cuts resulting in a transition from large to small disparity values or vice versa is unpleasant to the observers and should be limited as much as possible.

References

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