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Virtual Reality and Stereo Visualization in Artistic Heritage Reproduction

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Abstract

The use of different media from photography to virtual reality may provide a user with an extraordinary tool for appreciation and exploration of artistic heritage. This is especially important in case when direct perceptual experience is denied by distance to museums or prohibition of manipulating exhibits, and in case when a specific media may provide a user with extra functionalities. The use of a specific media such as virtual reality is very important in case of time-spatial work-of-art where the problem of functionalities presentation becomes much more demanding. The goal of the presented work is to contribute in assessing the role of different visualization technologies in work-of-art reproduction focusing on the use of virtual reality and stereoscopic viewing. Our main testing application reproduces a time-spatial work-of-art which contains multi-level mirror reflections and where gravity is also accounted for in the physical simulation. This application has been chosen because it inherently calls for user interaction, which challenges reproduction fidelity and real-time response. The resulting visual reproduction is analyzed for different display technologies and stereo viewing approaches. Results from sets of test trials ran on five different virtual reality systems, from 3D Laptop to Head Mounted Display and large Panorama, confirmed benefits of stereo viewing and emphasized few aspects which represent a base for further investigation as well as a guide when designing specific systems for telepresence related to virtual museum applications and interactive space installations.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism I.3.5 [Computational Geometry and Object Modeling]: I.3.4 [Graphic Utilities]: Virtual device interfaces J.5 [Arts and Humanities]: Fine arts I.4 [Image Processing and Computer Vision]: general

1. Introduction

There is nothing better than perceptual experience with pieces of art. Museums are still noticeable attractions to visit. Whereas for paintings the visual experience can provide the viewer with all aspects the author intended to express, artistic heritage, especially contemporarily, goes beyond traditional paintings and very often comprises interactive, time changeable installations or sculptures (time-spatial works-of-art). These types of artworks call for fully interactive and preferably immersive environments, to reproduce object potential meaning and interpretation. Lack of sufficient exhibition conditions (e.g. lack of space for presenting all of pieces, installations which can not be touched in the museum) quite often makes experimenting with pieces-of-art unavailable to people. A kind of remedy to the problem is making a sophisticated multi-media multimodal presentation being a substitute of a real object and providing user with wide variety of experiences. Among main media employed in artwork presentation: paper descriptions, photographs, films, computer animation, virtual reality (VR). The role of the chosen media depends on the object characteristics and the experience wished to be provided to a user. Assessing the role of different media in artwork presentation would clearly represent an important activity, which provides useful knowledge to be considered when designing cultural heritage reproduction. In the presented work we intend to contribute in assessing the role of different visualization technologies in work-of-art reproduction. The focus is also on the use of virtual reality in artistic heritage, which is under-represented in the literature, with the objective of analyzing the main 3 tasks to consider when creating a virtual museum applications: photorealistic reproduction, physical simulation, interaction with objects. A special attention is eventually paid to analyze user sense of presence and viewing experience for different VR systems, an aspect strongly related to display technology and stereo visualization. Time-spatial works-of-art are especially discussed and used as main testing application because they inherently call for user interaction, which challenges reproduction fidelity and real-time response.

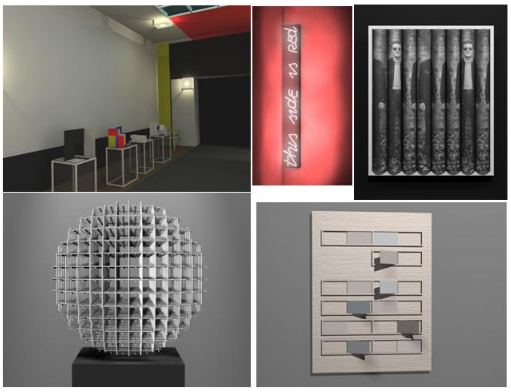

Figure 1: *The different contemporary pieces of artistic heritage which were considered.*

2. Multi-Media Presentation of Work-of-Art

Different media may be used for visual presentation of real work of art. In our analysis we consider: photography, film (motion-picture), computer animation, virtual reality. In case of photographs the 3rd dimension becomes reduced and so spatial features can be just imagined. By multiplying the number of photos connected with different viewpoints, more information can be revealed. Unfortunately such mean of presentation is incomplete due to its discontinuity and lack of thorough object observation possibility. Nevertheless, interesting efforts to overcome this limitation can be found in recent literature, [SSS06]. Another form of presentation is through motion capture and computer animations. Films and animations can more thoroughly retrieve time and spatial object features but at the same time they limit perspective and duration of the presentation. The user can not much influence presentation chronology except for stopping it, rewinding, pausing, or playing it slower. The captured images should be high-quality and entertaining. In case of virtual animation this means graphical appeal and high-quality rendering. Computer animation provides much more possibilities, but in comparison with a film it has still not acceptable image sterility. The use of virtual reality can well complement other media and it is especially important in case of time-spatial works-of-art because of the need for interaction. Even though the most advanced virtual reality simulation can not create fully photo-realistic copy of the original, digital reproductions let the user fully experience object functionality and it could become an introductory step towards real object perception. That is why reproductions play an important role in art propagation, and it is in particular the "exploration layer", [WKP02], which provides a user with an illusion of interaction with a real object by means of its reproduction. Interactive applications usually render less accurate graphics, finding the best trade-offs between image quality and real-time performance. The user will be given the instruments to change the configuration of the object of interest at his/her will, without breaking object's physical constraints. The user should be able to interact with the object with a simple and intuitive use of common input peripherals as the mouse or the keyboard, and change the viewpoint.

3. Interactive Works-of-Art

The works of art express internal author's attitude stimulate, shake and strike the spectator's interest and creativity giving him/her satisfaction. In case of time-spatial works-of-art, the aesthetical experience is not only connected with external appearance but with internal functionalities conceptualization as well. The role of VR representation as a media for artwork functionalities presentation becomes then very relevant and demanding. In fact, virtual world presentation can be treated as object simulation rather then object reproduction. Different contemporary pieces of artistic heritage were considered (figure 1). We have then chosen the MirrorCube as our main testing application because it inherently calls for user interaction in order to be appreciated, which challenges reproduction fidelity and real-time response. Furthermore, the chosen object poses some challenges for what concerns photo-realistic reproduction and physical simulation, it appears suitable for VR systems comparison, and it emphasizes the VR technology added value. The MirrorCube is a 6-sided parallelogram, a cube, which contains six mirrors, such that each mirror fully covers the internal part of each cube side, (figure 2). This transformable installation provides a viewer with different operational and interpretational possibilities. Simple element joints assure wide spatial transformation possibilities. The usage of the mirrors for object's construction leads to a specific game between real elements of the installations (mirrors, wooden stick fixed to the mirror surface, lines painted on the external side of mirrors) and their reflections. There has been an interest in the recent time among researchers in the thematic related to time-spatial works of art [MP02], [WKP02]. P. Patyra [Pat05] investigates the J. Robakowski "Mirror's Ball". The object consists of two elements: the spherical mirror and the ball. There could be observed the distorted reflection of the ball in the mirror, together with reflected surroundings. The ball is covered by the photos. The viewer can move the ball, (which rolls on the mirror surface following an elliptic path), so changing the reflection in the mirror. Even though mentioned authors discussed problem of works-of-art presentation quite thoroughly, none of them tackle the problem of multi-level

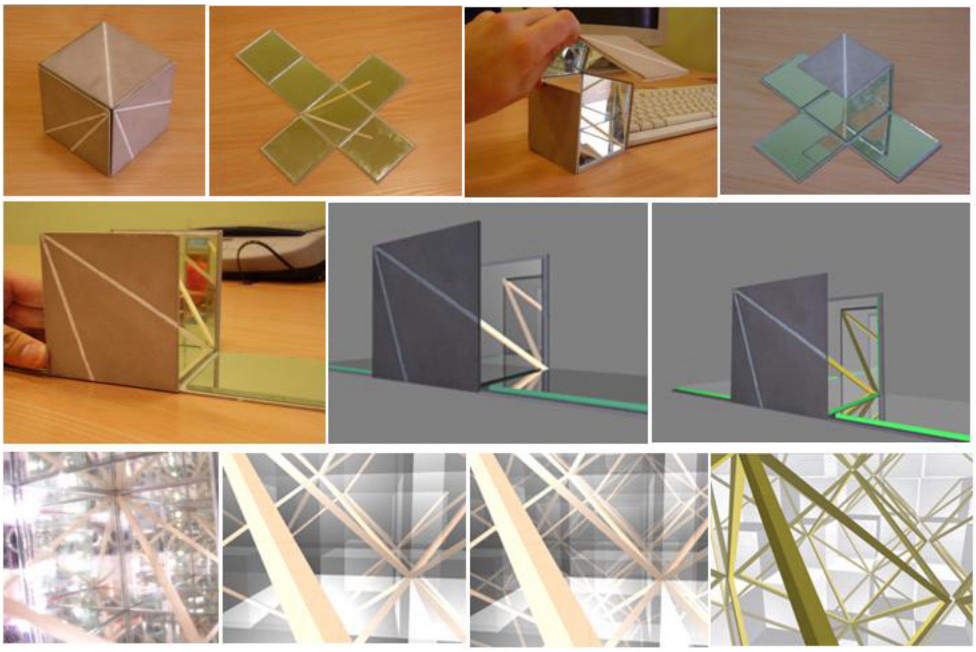

Figure 2: *The Mirror-Cube: exterior appearance and functionality (top-row), artistic nature (center row), infinite reflections (bottom-row). Center-row from left: photograph, raytraced with Mental Ray, rendered with OpenGL. Bottom-row shows multiple reflections. From left: photograph, raytraced with reflection limit 5, limit 8, rendered with OpenGL and 8 levels of reflections.*

reflections. None solve the problem of interaction with installations comprising mirrors at high satisfactory level. This paper presents complementary attitude towards presentation of artworks in which reflections play a main role and considerably influence installation perception.

4. Stereoscopic Visualization and Display Systems

The media mentioned in section 2 may be displayed in stereo called as 3D photograph, 3D movie, 3D animation, 3D interaction. The possibility for stereo visualization represents an important aspects which is lately receiving greater interests. This due to the spread of VR applications, improved visualization performance and more powerful graphic hardware at lower cost. Stereoscopic visualization is closer to the way we naturally see the world, which tells us about its great potential in VR applications. Stereoscopy is about the eyes seeing 2 slightly different images. Different technologies have then been developed to separate the images seen by the eyes. Main approaches may be classified as:

- *Passive Stereo*. Multiplex images in space and can be subdivided in: "Anaglyph" (separation based on color filters); "Polarized" (separation based on polarized filters); "Separated Displays" (separation based on the use of different displays very close to user eye, as in HMD systems).
- *Active Stereo*. Multiplex images in time typically based on "Shutter Glasses".
- *Autostereoscopic Stereo*. Separates images based on special reflecting sheets laying on the display, or other methods. Do not require users to wear goggles.

Different stereoscopic approaches can be used coupled to different display systems, [LP06]. The latter responsible for the provided degree of immersion, interactivity level, isolation from surrounding world, etc. Researchers in the literature have investigated the benefits of stereoscopy for different application aspects and depth cues. The literature works can be classified as either application specific, or abstract test, (abstract tasks and content with general performance criteria), [DJK*06]. In literature test trials often deal with assessing the role of most dominant depth cues, e.g. interposition, binocular disparity, movement parallax, [NM06], and their consequence to user adaptation to new context (user learning capabilities). The parameters through which assess stereoscopy benefits typically are: item difficulty and user experience, accuracy and performance speed, [NM06], [Dra91]. Everybody seems to agree that stereoscopic visualization presents the necessary information in a more natural form than monoscopic visualization, which facilitates all human-machine interaction [Dra91], and improve the possibilities of visualization offered by common 2D graphics workstations, [GB01]. In particular, stereoscopy improves: comprehension and appreciation of presented visual input, perception of structure in visually complex scenes, spatial localization, motion judgement, concentration on different

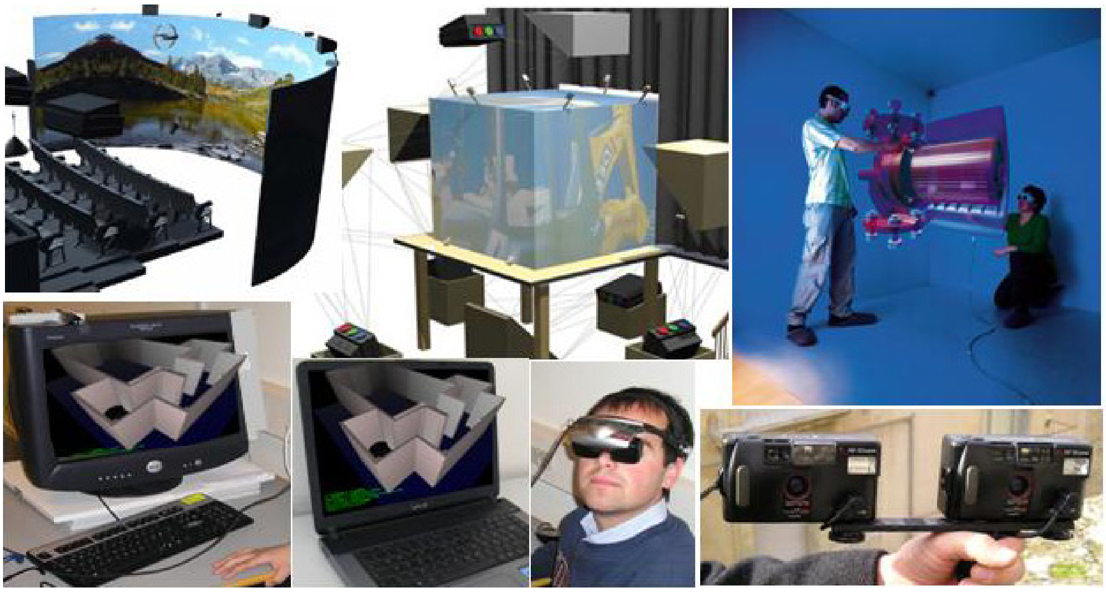

Figure 3: *Virtual reality facilities at the Aalborg University VR Media Lab and Medialogy Copenhagen. Top-row from left: 160 deg. Panorama, the structure of the CAVE, and a representative view it. Bottom-row from left: 3D Desktop, 3D Laptop, Head Mounted Display, 3D photo-cameras setup.*

depth planes, perception of surface materials. The main drawback with stereoscopic visualization, which have yet prevented large application, is that users are called to make some sacrifices, [SS99], [LP06].

5. Comparison of 3D Technologies

We have chosen among well known VR systems adopting different stereo approaches and display systems. At the Aalborg University we have a large variety of VR facilities, which represents a very suitable testing ground for our investigation (Figure 3 shows the VR facilities). In particular:

- *3D Laptop*. 15in high-res LCD display, passive anaglyph.
- *3D Desktop*. 21in CRT high-res monitor, both passive anaglyph and active shutters.
- *1-sided CAVE*. 2.5x2.5m rear-projected screens, high-res high-freq projectors, both passive anaglyph and active shutters. This facility is part of a pre-existing 6-sided CAVE (see fig. 4 top-left), so including head-tracking, etc.
- *Head Mounted Display*. 2x 0.59in OLED LCDs (800x600), separated displays stereo.
- *160 deg. Panorama*. 3x8m front-projected curved screen. High-res. projectors, active shutters.

In order to assess support of different VR systems in time-spatial works-of-art reproduction a series of comparative user studies are proposed to be run on the above mentioned facilities. The resulting visual reproduction is also compared with a typical outcome experienced with 3D photographs and 3D movies. Figure 3 shows the stereo photo-camera setup. A similar setup was used for 3D movies capture. With this study we assess systems capabilities for different display technologies. While performing comparative tests the users are asked to report about their experience through questionnaires. Questions are grouped into 5 judgement categories: *adequacy to application*, *realism*, *presence*, *3D impression*, *viewing comfort*.

6. Testing

6.1. Implementation, Image Quality and Speed

Over 160 pictures were taken with cameras with different resolutions. The pictures were grouped into 4 sets according to the following concepts: exterior appearance, functionality, artistic nature, infinite reflections. Figure 2 illustrates the above concepts. The animated video sequences of the object are modeled with Maya and rendered with Mental Ray. The resulting pictures are elaborated in Adobe Photoshop while animation sequences are converted with Adobe Premiere into movie files. Final presentation was based on a well defined storyboard. The interactive application is implemented in OpenGL which also simulates mirror reflections by the use of the stencil buffer. Multiple mirror reflections are added by means of recursive approach. The Mirror Cube modeled with Maya is imported into OpenGL and then interactively rendered. Object faces' physical simulation provides gravity acceleration of rotating mirror faces. The Stencil buffer which is now popular in commercial graphics cards, solves the reflection problem up to a relatively small number of nested reflections, and all mirrors ac-

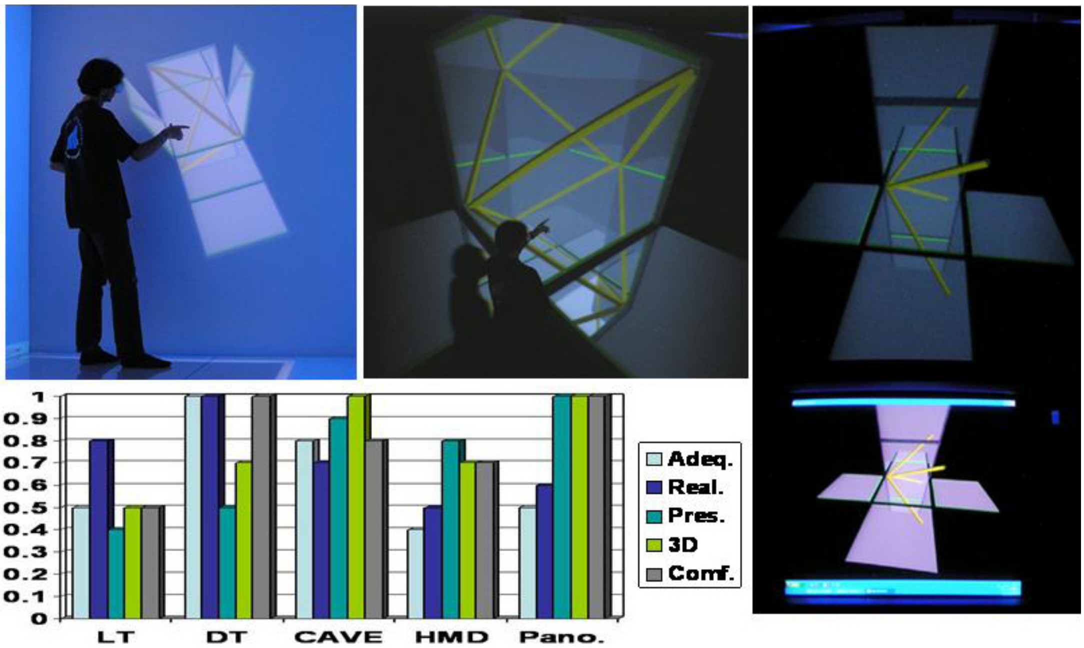

Figure 4: *The simulated Mirror-Cube in the CAVE environment (top-left) and Panorama (top-center). The left-picture shows a setup for concurrent comparison of Panorama and 3D Desktop images. The table summarizes comparative test results. The horizontal axis represents system considered: (LT) 3D Laptop with passive anaglyph, (DT) 3D Desktop with active shutters, (CAVE) CAVE system, (HMD) HMD, (Pano.) Panorama. The vertical axis summarizes users response on 5 different categories.*

curately reflect the scene and the other mirrors image. The use of the Stencil buffer in OpenGL allows for fast rendering being both stencil and depth test hardware implemented. The use of the Stencil buffer approach increases the illumination level in the scene as consequence of the mirror reflection, [Kil99], (a problem not present when using raytracing). The quality of the rendered images is observed by comparing real and computer-generated images, (figure 2). Surprisingly, the general quality of the images rendered in OpenGL (by polygonal verteces interpolation) is not far from that of the images generated in Maya (per-pixel raytracing). Concerning the rendering of the reflections, these are correctly drawn for both rendering techniques, however a more accurate light calculation makes a greater difference. Interesting, in case of screen-shots taken inside the closed cube, the reflections are identical. The responsiveness of the application to input commands changes for different platforms. There is a maximum level of reflection above which response speed is unacceptable (8 reflections on our Laptop). Concerning the gravity simulation the use of a friction was necessary.

6.2. Testing Displays Technologies

The results of the Comparative tests based on extensive testing trials related to the virtual interaction, ran by 5 VR experienced users, are summarized in figure 4.

Adequacy to application. The CAVE seemed very suitable as interactive gallery. In fact, already by moving around head and body a user can "play" with the artwork. The Panorama also offers good feedback but mostly for an expert user (interaction is through 3D mouse). The 3D Desktop provides a different type of interaction, and it was believed the most suitable for low cost remote-user interaction, and still better than 3D Laptop because of the possibility for using active shutters.

Realism. Large visualization screens provide higher Realism when passive anaglyph is not adopted. High realism with the Panorama, but better with CAVE thanks to the head-couple tracking. Details are difficult to catch when user stays very close to big screens. In case of Panorama the above effect diminishes being that user sitting at predefined distances. If we focus on comparing the rendered visual effect with the real one (when having object in hand) the 3D desktop gives the best result. This goes along with theories in [DJK*06], being this a "looking-in" task, i.e. when the user sees the world from outside-in.

Presence. The larger screen VR facilities provides the best result in relation to sense of presence, (as expected). Interestingly, the user involvment decreases in the case of the passive stereo anaglyph. This seems to be mostly justified by eye-strain arising from rear-projection (screen alters colors causing high ghosting). Passive anaglyph performs slightly better on real images, mostly due to a higher level of Realism.

3D Impression. It may surprise the reader that some users claim a high 3D Impression with 3D Desktop. Confirmation of 3D Desktop perceived 3D Impression can be found in [JLHE00], showing how the range of depth tolerated before loss of stereo fusion can be quite large. The CAVE and Panorama gives best impression for negative parallax (in front of display), which is very important in case the considered testing object is small. The 3D desktop also gives great performance. In case when the user exploits the VR added functionalities (not available in reality), e.g. object displayed in big dimension, or a virtual navigation inside the object, the CAVE and Panorama gives best performance.

Viewing Comfort. The highest Comfort judgement is assigned to 3D desktop with shutters and the Panorama, as confirmation of the benefits of front-projection in terms of image quality. Head-tracked displays may produce some disturbing effect (nausea). The passive anaglyph technology strongly affects viewing comfort. It is acceptable in case of 3D Desktop and Laptop, but it calls for high brightness, and unacceptable in the CAVE where high crosstalk arises from rear-projection.

The above results for the virtual interaction can be compared with general test-user impressions related to virtual animation, 3D movies, and 3D Photographs.

Virtual Animation. The Adequacy to application is generally much lower is case of animation due to the interactive nature of the object which is not represented. A higher level of Realism is always provided by the 3D Animation (compared to virtual interaction). This due to the raytracing based rendering. Still, the realism is lower than films or photographs. The viewing comfort is generally higher with animations than with interaction.

3D Movies. The impressions gathered when users were looking at 3D movies of various type showed a general improvement in user judgement in terms of (photo)-realism (as expected). The 3D films were highly appreciated in the CAVE, (as much as the synthetic images), then on the HMD, (which provided bright images and good color reproduction), and then on the 3D Desktop in case of active stereo. Passive anaglyph both on the 3D Desktop and CAVE lower image quality which is claimed to provide less realism. The 3D Impression were judged best in the CAVE in case of negative parallax, and the performance on the 3D Desktop was very good (particularly negative parallax). The HMD provided strong depth impression.

3D Photographs. When using high-quality photo-cameras and dias and separated display stereo for visualization, the Realism is the highest. This due to high-definition photo-realistic textures. 3D Impression can be very high for close objects. Viewing Comfort is also very high if active stereo is adopted or in case of separated displays. Naturally, 3D Photographs lack dynamics, which lower the sense of presence. A sensitive parameter affecting Realism is the distance between camera (baseline) which may cause the visualized object to appear "cartoon-like". The same aspect may however contribute in providing a stronger 3D impression.

A more thorough comparison is a work in progress.

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