The Effect of Quality of Rendering on User Lighting Impressions and Presence in Virtual Environments

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Abstract

A between groups experiment was carried out to explore the effect of rendering quality on subjective impressions of illumination and perceived presence after exposure to a Virtual Environment (VE). The computer graphics scenes were rendered in varied levels of shadow accuracy utilising flat-shaded and radiosity rendering and were displayed on a stereo, head tracked Head Mounted Display (HMD). A total of 36 participants were exposed to each experimental visual condition and after completing a spatial task, they were given two questionnaires: A presence questionnaire and a questionnaire investigating subjective responses to lighting. Relevant results show a positive correlation between presence and subjective impressions of lighting (e.g. 'warm', 'comfortable', 'spacious', etc.) associated to the high-quality, full-shadow accuracy rendering condition. How real-world responses for both presence and lighting could be incorporated into a computer graphics simulation is still an open research question.

Keywords
Human Factors, Virtual Environments, Illumination, Simulation, Presence.

1 Introduction

It is not computationally feasible to immerse an observer into an *interactive* artificial environment which mimics the panoply and complexity of sensory experiences associated with a real-world scene. For a start, it is technologically challenging to control all of the sensory modalities to render the exactly equivalent sensory array as that produced by real world interaction [Billinghurst et al. 2002; Mania & Chalmers 2001; Mania et al. 2003; Biocca et al 2002].

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Perceptual fidelity is not necessarily equivalent to physical simulation. The ultimate goal, as often argued, is to create synthetic spaces that are going to induce a sense of 'presence' similar to the real world. This goal would not necessarily be achieved by accurately simulating real-world spaces and illumination. Building a Virtual Environment (VE) system to match the human perceptual and motor systems is essential. Generally, for any given task or for any application that requires a high level of simulation fidelity and mainly targets, for instance, transfer of training in the real world, the ability to induce spatial awareness and impressions as in the real world could be significant for any task situation.

Light has the obvious function of providing visibility for visual task performance. Flynn 1975; 1977 however, argues that lighting properties should begin with the overall user well being, the visual quality of a room and should not be limited to task visibility. Generally, acquiring human responses to lighting indicate a move towards assessing lighting designs from an impression point of view rather than a task point of view. One could argue that the presence related research for VE technologies is striving to achieve similar goals: to assess a software platform or a virtual interface generically, not by necessary linking this assessment with task performance although the relationship between presence and task performance is often considered crucial. One of the goals of a significant paper by Rushmeier et al. 1995 on perceptual image quality metrics was to relate subjective impressions of an environment to values computed from measured luminance images [Rushmeier et al. 1995]. In a previous study comparing memory performance in a real-world space and a photorealistic simulation of that space based on photometry data, the perceived level of presence correlated positively with feelings of warmth, comfort, simplicity, uniformity and spacious space for the monocular conditions displayed on a Head Mounted Display (HMD) including either the common mouse or head tracking as interaction interfaces [Mania 2001]. In a more recent study focused on comparability of real and virtual environments for environmental psychology, factor analytic dimensions of evaluation, ambience, privacy and security were similar for both real and VEs, however, a fifth dimension termed arousal was absent in the VE. In this case, the virtual environment was rendered flat-shaded. It is valuable to identify whether statistical correlations exist between lighting impressions and perceived presence in an experiment that investigates the effect of rendering quality ranging from flat-shaded to levels of radiosity computations. The study presented in this paper utilise human responses to illumination in order to

assess the simulation fidelity of computer graphics scenes of varied rendering quality. The scenes were displayed on a head-tracked HMD in stereo.

2 Background

2.1 Presence

What sets VE technology apart from its ancestors is that in VE systems users can receive a number of distinct multi-sensory stimuli (i.e., visual, auditory, haptic) which are intended to provide a sensation of 'natural' interaction with the virtual world and, consequently, an illusion of being 'present' in a VE. 'Presence' generally, refers to the sense of being present in time or space in a particular location (Webster's II Dictionary, 1984). In the world of media and emergent technologies such as video conferencing, high definition television and home theatre, presence is defined as the perceptual illusion of non-mediation [Lombard & Ditton 1997]. An 'illusion of non-mediation' occurs when the user fails to perceive the existence of a medium in his/her communication environment and reacts as he/she would if the medium were not there. Presence in VEs can be explained as the participant's sense of 'being there' in a VE; the degree to which the users feel that they are somewhere other than they physically are while experiencing a computer generated simulation [Shloerb 1995].

Varied perceived presence measurement 'devices' have been employed in literature. Loomis 1992 observed human response to events that in the natural world would provoke 'reflex' reactions. For example, if a one is sitting in front of a screen and experiences a scene of a car moving towards him/her very fast, then he/she might be 'forced' to turn to the right or left, in order to avoid 'collision' responding to the moving image as if it was occurring in reality. Another way of measuring presence introducing a quantitative strategy was proposed by Schloerb 1995. This method is based on a user's inability to discriminate between a real and a VE and proposed the addition of certain types of 'noise' to a real image until it is impossible to be distinguished from the virtual image. Slater et al. recently introduced a measure of presence based on self-report of 'Breaks in Presence' while a participant experiences a VE simulation [Slater & Steed 1998]. Also, physiological measures as blood pressure and heart rate have been employed [Meehan 2001]. According to Frederick Brooks, one of the 'hot, open challenges' is to measure the degree of presence and its operational effectiveness [Brooks 1999].

The most common method for measuring presence is post-experiment self-report. The study presented here employed several questions included in the Slater et al. questionnaire [Slater et al. 1998]. These questions are associated with the notion of presence itself and not with any characteristics of the technology. Hence, it could be applied to the real world as well as to the desktop and HMD conditions. For example, the participant rates the extent during the experience that the particular 'space' of the application is the dominant reality as well as their level of

perceiving the VE as a 'locality' or a 'place' that was visited rather than merely seen.

2.2 Subjective Responses to Lighting

Flynn 1975; 1977 noted that many lighting systems are designed merely to function in a 'permissive' way, i.e. simply to permit performance or participation in some activity that involves vision, without attempting to influence participants impressions or behaviour. Many lighting designs, however, especially in a commercial context may intentionally or unintentionally function more actively as shifting selectively human visual experiences: focusing attention, guiding circulation and generally affecting impressions of a room or task situation. The author suggests a procedure for investigating the effect of light on impressions and behaviour based on the use of Semantic Differential (SD) rating scales, including adjectives such as 'clear-hazy', 'pleasant-unpleasant', etc. Work with such scales has identified several broad categories of impression that can be applied to lighting. The categories of impression of particular interest are:

- *Perceptual* categories such as visual clarity, spaciousness, spatial complexity, colour tone, glare.

- *Behaviour* setting categories such as public vs. private space, impressions of relaxing vs. tense space.

- *Overall preference* impressions such as impressions of like vs. dislike or impressions of pleasantness.

Subjective impressions of lighting have proved to be similar when utilizing similar light settings in different rooms and with different object arrangements or activity settings indicating that the modifying effect of lighting is consistent across rooms [Flynn 1975]. This reinforces the theory that subjective impressions are more a function of the actual lighting characteristics than the actual environment in question.

3   Methods

3.1 Participants and visual conditions

Three groups of 12 participants were recruited from the University of Sussex, UK postgraduate population. 80% of the participants from each group were male. All used computers a great deal in their daily activities. A between-subject design was utilised balancing groups for age and gender. Participants in all conditions were naive as to the purpose of the experiment. Participants had either normal or corrected-to-normal vision (self–report). According to the group they were assigned to, participants completed the same memory task in one of the following conditions:

- Using an interactive radiosity computer graphics simulation of an office on a stereo head-tracked Head Mounted Display (HMD); referred to as the **high-quality condition** (80% radiosity iterations)

- Using an interactive radiosity computer graphics simulation of the same office on a stereo head-tracked HMD; referred to as the **mid-quality condition** (40% radiosity iterations)

- Using a low quality, interactive flat shaded computer graphics simulation of the same office on a stereo head-tracked HMD; referred to as the **low-quality condition**

Each environment varied considerably with regard to shadows. The flat-shaded environment did not include any. Radiosity algorithms, however, display view-independent diffuse interreflections in a scene assuming the conservation of light energy in a closed environment (Figure 1). All energy emitted or reflected by every surface is accounted for by its reflection from or absorption by other surfaces. Radiosity methods allow any surface to emit light; thus, all light sources are modelled inherently as having area. The surfaces of a scene are broken up into a finite number of n discrete patches, each of which is assumed to be of finite size, emitting and reflecting light uniformly over its entire area. The result of a radiosity solution is an interactive three-dimensional representation of light energy in an environment allowing for soft shadows and colour bleeding that contribute towards a photorealistic (diffuse) image. No specular reflections are computed. The luminance level of the scene (brightness) was also constant across conditions (Figure 1).

The environment of the mid-quality condition was a result of 40% radiosity iterations. The environment of the high-quality condition was a result of 80% of available radiosity iterations. In all cases, a single ceiling mounted light source was used. The basic model construct was identical and the contents and room layout remained unchanged in each condition. The level of luminance of the scene was constant across conditions.

The computer graphics application was displayed on a Kaiser Pro-View 30 head tracked HMD (Figure 2) and the application was driven by a PC with an average-cost graphics card. The Field of View (FoV) of this display is 30 degrees diagonal. The experimental space consisted of a room, representing an academic's office including various objects (Figure 1). The radiosity rendering process described above resulted in three distinct models of varying polygon count. The geometric models of the scene were used to generate VRML (Virtual Reality Mark-up Language) environments, which were imported into WorldUP - a proprietary VR authoring software package. WorldUP allows simulation of specific behaviour to be added in order to control the interaction with the synthetic scene. Given the nature of the three environments and the research undertaken here, the ability to control the way in which participants interacted with the simulations was crucial. The viewpoint was set in the middle of the virtual room and navigation was restricted to a 360 degrees circle around that viewpoint and 180 degrees vertically (rotation). Participants were sitting on a swivel chair during exposure.

Due to the increased polygon count, the high-quality radiosity environment placed a greater computation demand, therefore, it could not be rendered and displayed in real-time as rapidly as either the mid-quality or low-quality versions. In order to maintain parity with regard to the display and update speed of each environment given the differing levels of computational load, the maximum frame-rate of the high-quality environment was ascertained via the use of a simple frame-rate counter, at 12 frames per second (fps). The frame rate was kept constant across conditions. A simple subsystem calculated the actual frame rate the selected environment was running at, compared this to the desired 12 fps and paused the simulation for the amount of time corresponding to the differential in frame-rate. This subsystem was run by the simulation once every frame, thus maintaining a constant 12 fps regardless of the environment.

3.2 Procedures

Each of the three environments was presented in stereoscopic 3D by employing a dual channel video subsystem. The Inter Pupilary Distance (IPD) of each participant was measured prior to exposure and the application's parallax was adjusted accordingly for each individual. This had an impact on the achievable frame-rate since each polygon position must be calculated twice, once based upon the view direction detected via the head tracker and again based upon the same information plus the parallax differential. The results of such techniques are visibly impressive, but may contribute to the average frame-rate (12fps) that was observed during the experimental simulation which, however, was considered adequate.

The exposure time was 45 seconds across conditions. At the start of the simulation a pop-up window was generated utilised to acquire each participant's ID. Once the ID had been entered, the window was removed and a timer started. When this timer indicated that the 45 seconds of exposure had expired, the simulation was shut down automatically, ensuring that each test participant was restricted to exactly 45 seconds of exposure to the environment.

The room where the experiment was taking place was kept dark during exposure. Participants were led to believe that this was just a test phase of the main experiment, therefore, they were not aware of the experimental task prior to exposure. Participants were also given identical instructions across conditions.

Participants were instructed to look around the room. After 45 seconds exposure to the VE, the two groups of participants were administered the Simulator sickness questionnaire (SSQ) [Kennedy et al. 1993] before and after exposure, the subjective lighting impressions questionnaire as well as perceived presence questionnaire [Slater et al. 1998]. Although this study did not include systems necessary to track eye movement, a record of each participant's head movement was monitored through software. Whilst this information is not at a high enough resolution to be useful in determining the time spent looking at each object in the room, the amount and location of participants' idle time was monitored so as to ascertain that it was similar across visual conditions. A measurement was taken once every 4 frames, providing 3 measurements every second across all conditions [Mania & Randell 2002].

Figure 2. Experimental set-up.

spacious	1	2	3	4	5	6	7	confined
relaxing	1	2	3	4	5	6	7	tense
bright	1	2	3	4	5	6	7	dim
stimulating	1	2	3	4	5	6	7	subduing
interesting	1	2	3	4	5	6	7	uninteresting
radiant	1	2	3	4	5	6	7	gloomy
large	1	2	3	4	5	6	7	small
like	1	2	3	4	5	6	7	dislike
simple	1	2	3	4	5	6	7	complex
warm	1	2	3	4	5	6	7	cold
pleasant	1	2	3	4	5	6	7	unpleasant
comfortable	1	2	3	4	5	6	7	uncomfortable

Table 1: List of bipolar adjectives representing subjective lighting impressions.

3.3 Materials

The following questions were included in the Presence questionnaire administered to participants after exposure, taken from [Slater et al. 1998]:

- Rate your sense of being in the 3D room, where 5 represents your normal experience of being in a place (1=Not at all. 5= very much)

- To what extent were there times during the experience when the 3D room was reality for you (1=not at all. 5= Most of the time)

- When you think back about your experience, do you think of the 3D room more as images that you have seen or more somewhere that you visited (1= images. 5= a place visited)

Figure 1. Flat-shaded rendering (above), mid-quality radiosity rendering (middle) and high quality radiosity rendering (last).

The following questionnaire was also administered to participants including bipolar adjectives related to participants' subjective impressions of the illumination and the space (Table 1). Instructions were given as follows:

'The following questions relate to your impression of the 3D room. Please, circle the appropriate step on the scale from 1 to 7, for each question ':

4 Results

The presence questionnaire was administered to the three groups (between groups experimental design). Presence data were analysed using a comparison of means before carrying out an ANOVA across conditions [3]. The memory recognition scores were analysed using **AN**alysis of **VA**riance (ANOVA). ANOVA is a powerful set of procedures used for testing significance where two or more conditions are used. Significance decisions involve rejecting or retaining the null hypothesis (which claims that groups are identical). The null hypothesis is rejected when the probability that a result occurring under it is less than .05. In addition to this generic analysis and to avoid the theoretical problem of ordinal data, a binomial regression analysis was employed based on the count of high scores for the presence questions and following the analysis explained in the Slater et al. study [14]. This method verified the results related to significant differences identified by the generic ANOVA analysis.

An overall effect of condition was not revealed for the perceived presence dataset. This is in accordance with similar results in previous studies [Mania et al. 2003; Mania & Chalmers 2001; Mania 2001; Usoh et al. 2000]. The overall means for presence are shown in Table 2.

	Presence	Lighting impressions
Low quality	2.77	4.00
Mid-quality	2.86	3.47
High quality	2.66	3.46

Table 2. Overall means for presence and lighting impressions across visual conditions.

The presence measuring device employed either failed to pick up an effect of condition upon presence or there was not an effect of condition across conditions. Only a concrete understanding of presence, in a way that will allow formal assessments of its perceived level in experimental studies such as this one (if this is ever possible or desirable) will aid towards forming relevant conclusions.

The rendering quality did not prove to have a significant effect upon the subjective impressions of lighting dataset. The relevant means are shown in Table 1. This is not a surprising result since the luminance level of the scene as well as the display was the same across conditions, despite the varied shadow accuracy.

A statistically significant positive correlation was revealed, however, between the subjective responses to lighting dataset and the presence dataset for the high quality radiosity condition (r=-0.54, Pearson's correlation, $p<0.05$; Spearman's correlation, $p<0.05$). According to these correlation a high level of perceived presence resulted in a high rating of 'comfort', 'warmth', 'spacious' feeling and 'relaxing' feeling associated with subjective responses to lighting, for the high quality condition. For this phenomenon to be verified and fully explained, a study that would focus on validating these results should be designed.

Monitoring navigational strategies (idle time) was based on the assumption that the head tracker was recording directional co-ordinates that could vary around 180 degrees (the Field-of-View of the human visual system). Navigation was monitored for horizontal and vertical actions. When participants were idle, their attention was assumed to be directed to the visible space based on the FoV of the display and visual angle. The average idle time was 20 seconds. There was not a significant difference for idle time and positioning of idle time during exposure across conditions, horizontally, $F(2,35)=0.589$, $p<0.05$, or vertically, $F(2,35)=0.972$, $p<0.05$. If idle time significantly differed across conditions, results would have not been comparable.

Simulator sickness symptomatology ratings were very small due to the short exposure to the VE.

5 Discussion

A theory for lighting design as discussed above argues that light cues signal subjective associations or impressions and that the direction of these impressions is somewhat independent of the room in which the light cues are viewed [Flynn 1975; 1977]. It could be hypothesised that by accurately simulating the illumination in the real world to match the illumination in a synthetic space, subjective responses to lighting may vary depending on the accuracy of the computer graphics rendering and the fidelity of the VE (display, field-of-view, tracking, system design). However, such subjective reports might be independent of physics-based simulations.

In a previous study [Mania 2001], the computer graphics rendering was retained the same across varied displays and interfaces involved such as a desktop monitor vs a HMD, a mousse interface vs head tracking and mono vs stereo computer graphics rendering. Theoretically, if the participants' response is similar across conditions for the same dynamic computer graphics scene, this could be a step towards validating the metric that could be subsequently used for assessing subjective responses to varied lighting or rendering quality scenes. Interestingly, in that study, the perceived level of presence correlated positively with feelings of warmth, comfort, simplicity, uniformity and spacious space for the monocular conditions displayed on the HMD in conditions including either a common mouse or head tracking as interaction interfaces. This indicates that participants with a high sense of presence communicated a high level of subjective impressions such comfort, warmth, spaciousness, etc. The display, in that case, the HMD, proved to be a significant factor for this significant correlation.

In the study presented here, we are exploring the effect of the quality of rendering and in particular, shadow accuracy, employing the radiosity algorithm. There was no effect of condition upon the presence and the lighting impressions datasets indicating that shadow accuracy did not affect participants' sense of presence and their level of comfort, warmth etc. related to their subjective impressions of the illumination. It is worth noting here, that the luminance level was retained the same across visual conditions, despite the varied quality of rendering. Luminance levels which correspond to the subjective impressions of brightness could be a significant factor that would yield significant differences. However, there was a positive correlation between presence and feelings of comfort and warmth (Table 1) associated only with the high quality of rendering. This indicates that when participants reported a high (low) level of presence, they similarly reported a high (low) level of positive subjective impressions to the lighting as expressed by the set of bipolar adjectives administered (Table 1). This correlation was only observed for the high-quality condition.

How real-world responses for both presence and lighting could be incorporated into a computer graphics simulation in addition to the geometry and illumination simulation, is still an open research question. Identifying ways to 'induce' reality rather than simulating the physics of reality is the greatest but also most fascinating research challenge of all.

6   References

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