Dynamic Intelligent Lighting for Directing Visual Attention in Interactive 3D Scenes

Magy Seif El-Nasr, Thanos Vasilakos, Chinmay Rao, and Joseph Zupko[1]

***Abstract*—Recent enhancements in real-time graphics have facilitated the design of high fidelity game environments with complex 3D worlds inhabited by animated characters. Under such settings, it is hard, especially for the untrained eyes, to attend to an object of interest. Neuroscience research as well as film and theatre practice identified several visual properties, such as contrast, orientation, and color that play a major role in channeling attention. In this paper, we discuss an adaptive lighting design system called ALVA (Adaptive Lighting for Visual Attention) that dynamically adjusts the lighting color and brightness to enhance visual attention within game environments using features identified by neuroscience, psychophysics, and visual design literature. We also discuss some preliminary results showing the utility of ALVA in directing player's attention to important elements in a fast paced 3D game, and thus enhancing the game experience especially for non-gamers who are not visually trained to spot objects or characters in such complex 3D worlds.**

***Index Terms*—lighting design, game lighting, graphics, intelligent lighting, and visual attention in games.**

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I. INTRODUCTION

Lighting plays an important role in the design of 3D virtual environments. Animators, filmmakers and theatre directors have discussed its importance in establishing visibility, evoking certain moods as well as in guiding participant's attention to important elements in a scene [1-3]. Neuroscience and psychophysics literature identified several visual attention features related to lighting, including contrast, eccentricity, and symmetry [3, 4]. Knowing these important functions of light, cinematic and theatric lighting designers developed techniques to continuously modulate scene lighting accommodating many of these important functions, including establishing visibility, and setting atmosphere [1].

Lighting design is as important for games and 3D environments as it is for film and theatre. Film and theatre lighting design techniques have been documented in many books available to public. In contrast, lighting design techniques and their functions in games received very little attention. One exemplar within this area is the work of Niedenthal [5, 6]. In his work he interviewed designers and reviewed several games to identify the role of lighting within games.

Niedenthal's studies, in addition to our interviews with game designers, allude to the importance of lighting design for games. Based on these studies, one can conclude that lighting design plays similar roles in games as it does in film and theatre, including directing visual attention, providing mood, and enabling visibility. However, these studies uncover several differences in game lighting design. The process and function of lighting design for games varies depending on game genre and mechanics. In games, designers need to lead the player through visual attention. For example, one designer we interviewed mentioned that for a spatial puzzle, lighting and texture is used heavily for visual attention. In addition, as discussed in Niedenthal's work, for stealth based games, lighting plays a vital role in enabling stealth based mechanics. This particular function was emphasized by Warren Spector in his description of the intelligent lighting system developed for *Theif III* [7].

Current methods for lighting design in games differentiate between lighting the environment and the characters within the environment. To light the environment, lighting designers pre-bake the lighting in textures or light maps using techniques, such as spherical harmonics, to establish a realistic look for the environment. Characters and objects are mostly lit dynamically, where each character has a group of attached lights that follow them around ensuring their visibility and depth within the environment.

None of the current methods, however, can dynamically and autonomously, at run-time, establish a balance between lighting color and brightness on characters or objects and the environment to ensure that characters are visually noticeable and can quickly capture player's visual attention, when needed. This is partly due to the separation between the environment lighting and character lighting processes. To ensure that an object or character of interest can attract attention, it is important for a designer to know what the environment lighting conditions look like such that he can balance the lighting colors and brightness on the character or object to complement the colors and brightness in the environment, thus creating the necessary contrast needed for visual attention. This is mostly done statically by designers or artists. However, when colors and brightness shift dynamically, this lighting function is not always maintained.

In this paper, we explore this particular problem. Specifically, we propose a new system called ALVA (Adaptive Lighting for Visual Attention) – an extension of ELE (Expressive Lighting Engine) [8, 9]. ELE is a dynamic intelligent lighting system that one of the authors developed in 2003. ELE adjusts lighting based on several film and theatre design rules to balance several lighting design goals, including visibility, aesthetics, and drama. ALVA extends ELE to include rules for manipulating lighting color based on neuroscience and psychophysics theories on visual attention. Thus, ALVA is a constraint optimization system that adapts lighting to portray visual focus while maintaining visual continuity using rules constructed based on theories of human perception.

This paper is divided into several sections. Section 2 discusses previous techniques used for lighting design including an in-depth description of ALVA's predecessor ELE. In section 3, we discuss visual attention theories that inform ALVA's algorithms and rules. Section 4 is devoted to discussing ALVA's algorithms and rules in detail. We follow this section with a discussion of two experiments we conducted to compare the use of ALVA and its impact on visual attention. Section 6 outlines the applications and contributions of ALVA on the gaming experience and participants' engagement. We then conclude by discussing implications of the work and future directions.

II. PREVIOUS WORK

Current lighting design in games, as revealed by our interviews, use static lighting methods for lighting the environment and dynamic lights for lighting characters since characters are dynamic. To light the environment and establish the level of aesthetic, realism, look and feel required for today's games, artists use 3D packages, such as Maya or 3D Max to develop lighting models for the environment using image-based lighting methods or other techniques such as spherical harmonics or hemispherical lighting to simulate the environment terrain. This lighting is then baked into the textures used for the environment. This method produces a static solution to environment lighting, but produces fast and aesthetically pleasing environments. To accommodate for the dynamic nature of the interactions, designers use dynamic lighting on characters, where several lights are attached to a character and follow him/her around ensuring their visibility and illusion of depth.

Unfortunately, these methods do not automatically or dynamically change to accommodate visual focus. In other words, the lighting on the characters/objects and the environment do not change to make the characters or objects stand out to grab attention. Most games use halos around objects of interest to grab attention. While this is a good solution for some objects and some genres, it does not provide a good solution for realistic designs where more subtle attention grabbers are needed.

Previous work on automatic lighting design systems for games received very little attention. We know of only one system that has attempted to develop an automated solution for adjusting lighting in real-time based on interaction. This system is called ELE (Expressive Lighting Engine), developed by one of the authors of this paper. ELE is a dynamic, intelligent lighting system based on cinematic and theatric lighting design theories. It uses constraint optimization algorithms to compose and adapt a lighting design dynamically and in real-time, accommodating user interaction while achieving artistic design goals. Design goals are entered as numeric constraints representing artistic constraints that can adapt to the changing dramatic and physical contexts.

ELE uses stage layout, scene graph information, and artistic constraints to create a light layout. ELE divides the scene into *n* different areas and then categorizes these areas as focus, non-focus, or background. This information is then used to achieve several artistic goals, such as increasing depth, modeling, and evoking mood by establishing visual contrast. To compute the light layout based on these goals, ELE minimizes a multi-objective function to determine the number of lights to use for each area:

$$p_{opt} = \arg\max_{p}\left(\lambda_v V(p) + \lambda_d D(p) + \lambda_m M(p) + \lambda_{vc} VC(p)\right),$$

where *p* is the light configuration and λ are weights representing constraints. Specifically, λ_v is the importance of visibility, λ_d is the importance of depth, λ_m is the importance of modeling, and λ_{vc} is the importance of visual continuity. *V(p)* is visibility given *p*, *D(p)* is depth given *p*, *M(p)* is modeling given *p*, and *VC(p)* is visual continuity given *p*.

In determining the angles of light, ELE also takes into account the use of light angles in projecting depth, modeling, and mood, where mood is evoked through the angle of light on a character. For example, a character can be lit from below, creating a sense of evil or mystery [10]. ELE uses non-linear optimization to select an angle for each key light that minimizes the following function:

$$\lambda_v (1 - V(k,s)) + \lambda_{-} \left|k - k^{-}\right| + \lambda_m \left|k - m\right| + \lambda_l \min_i \left|k - l_i\right|,$$

where *k* and *s* are defined as the key light azimuth angle relative to the camera and the subject angle relative to the key light. k^{-} is the key light azimuth angle from the previous frame and the λs represent artistic constraints. Specifically, λ_{-} is the cost of changing the key light angle over time (to enforce visual continuity), λ_m is the cost of deviation from the mood azimuth angle, *m* is the mood azimuth angle suggested by the artist, λ_l is the cost of azimuth angle deviation from a practical source direction, l_i is the azimuth angle of light emitted by the practical source *i*, and λ_v is the cost of deviation from an orientation of light that establishes best visibility.

The interaction of lighting colors in a scene composes the contrast and feeling of the entire image. Similar to the angle and layout systems, ELE uses a non-linear optimization to search through a nine-dimensional space of RGB values. It differentiates among focus colors, non-focus colors, and background areas to select a color for each individual light in the scene. The multi-objective cost function evaluates a color against the lighting design goals, including establishing depth, conforming to color-style and constraints, paralleling dramatic tension, adhering to desired hue, saturation, lightness, and maintaining visual continuity.

While ELE included a goal for manipulating visual focus, it did that through adjusting brightness of the focus area in comparison to the non-focus area. The problem with this approach is that it does not always generate the right results, especially when the non-focus areas are lit with very bright light. Instead, ALVA encodes several rules based on neuroscience and theatre methods, thus extending ELE's ability to manipulate the lighting specifically for visual focus.

Below we discuss visual attention theory to provide the reader with the basis for the rules developed for ALVA's decisions. We then discuss ALVA and the rules introduced to ELE's functionality.

III. VISUAL ATTENTION METHODS

Much work has been done on visual attention [10-19]. Visual attention models point to the existence of two processes: a bottom-up fast feature-based task-independent process, where viewers' attention is directed towards the most salient object in an environment based on the object's features, and a top-down task specific visual search whereby attention is directed towards an object based on the task at hand. Since the applicability and utility of using biological or psychological visual attention models in 3D environments has not yet been verified, as a first step in the proposed research, we will focus on the bottom-up feature-based process.

While there are many theories on visual attention, there are few computational models. As an example, we will review the first explicit biologically plausible visual attention computational model [12], which was later extended by Itti and Koch [14, 20, 21]. The model describes focal visual attention as a bottom-up process where the perceptual saliency of the stimuli critically depends on the surrounding context. Thus, the model produces a 'saliency map' that topographically encodes stimulus saliency over the visual scene given several features, including color, orientation, and motion, as documented by Treisman et al. [22]. Specifically, in terms of color features, Treisman's model discusses properties, such as warmth, brightness, and saturation, which determine saliency of a stimulus in regards to visual attention. For example, a warm colored stimulus will gain more attention than a cool colored stimulus. This, however, necessitates contrast to establish visual attention. For example, a warm colored stimulus in a room that is colored with equally warm textures will not establish visual attention. In addition, the model also includes an inhibition of return process by which the currently attended location is prevented from being attended again, and less salient stimulus becomes more salient.

This model was successful and effective in modeling the visual attention process. However, there are several limitations to the model. For example, the model does not account for the task-dependant top-down visual search process [13], which may eventually influence the attention process and direct users'/viewers' attention to other objects given the task.

In this article, we compose the algorithms for visual attention based primarily on lighting color and brightness, thus not accounting for motion or orientation features as described by Treissman. In addition, the algorithms will rely on the bottom up visual attention process rather than the top-down, which is a limitation of the approach. Since this is the first exploratory study that aims to use lighting in 3D interactive environments for channeling visual attention, we decided to first concentrate on the most basic form of visual attention and then later expand it to a more complicated mix of bottom-up and top-down processes.

IV. ADAPTIVE LIGHTING FOR VISUAL ATTENTION (ALVA)

We have redesigned ELE (Expressive Lighting Engine) [23, 24] developing a new system called ALVA (Adaptive Lighting for Visual Attention). ALVA adapts lighting specifically to direct participants' attention to important areas in real-time while maintaining visual continuity. The major difference between ALVA and ELE is in the rules and algorithms for handling visual attention. Also, ALVA includes rules based on game specific mechanics, while ELE is more general and requires authors to add layers of scripting to target its use for games.

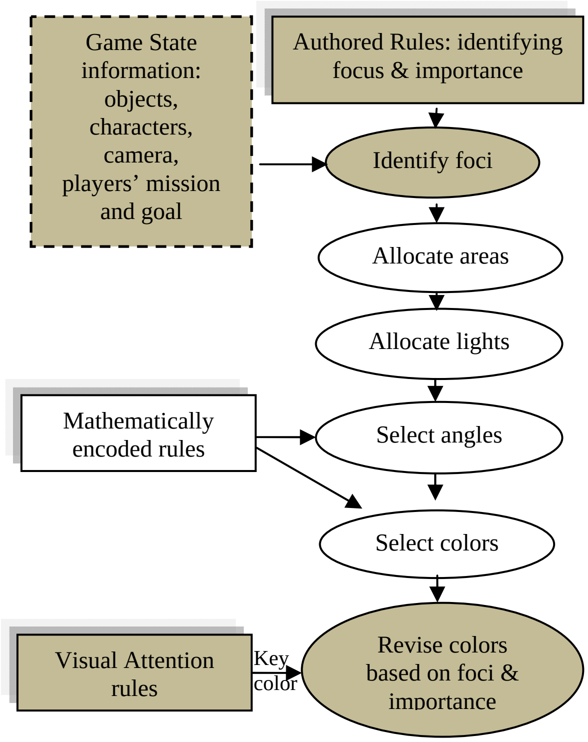

Figure 1. ALVA's Architecture, shaded areas are signify areas of enhancements on ELE

In this section, we will outline ALVA describing its mechanism for adjusting the lighting automatically in real-time responding to changes induced by interaction. It should be noted that ALVA is an enhancement on ELE, and thus it uses many of ELE's systems. Figure 1 shows the architecture for ALVA. We indicated the places (shaded in the figure) where ALVA adds a significant improvement to ELE. We will concentrate on these main shaded areas in this section.

A. *Layout*

To achieve and maintain visual attention, ALVA utilizes some game parameters, including level or zone configuration, quests, number of characters, number of objects within the scene, architectural points of importance, their dimensions, camera position, and anticipated movements. It uses these parameters to identify areas of visual focus. Unlike ELE, ALVA identifies these focus areas using authored rules that designers encode in the system. These rules identify when specific objects or characters become important and how important they are given a game state, player's goals, and missions. An example rule can be as follows:

```
(defrule
   trigger: (goal ?player (get key1))
   action: (attend-to questobjectID123 100))
```

where *questobjectID123* is a quest object related to the goal of getting *key1*. Thus, this rule indicates that if the player's goal is to get *key1* then the *questobjectID123* should be highlighted with 100% importance. Examples of important objects ALVA can highlight include:

- Visible Enemies
- Visible Quest objects
- Parts of a level identified by the designer as an object that can lead the player forward. This is important for platform games or spatial puzzles games like *Prince of Persia*

Based on these authored rules and the game state, ALVA creates focus areas, which are represented as cylinders around the important objects. Unlike ELE, ALVA assumes several areas of focus rather than just one focus area. It also gives each area an importance level. This is important for games, because most often there are several areas that are important for the players to attend to with different attention levels. ALVA first determines these focus points and their importance.

Like ELE, ALVA divides the visible area into several foreground areas depending on the maximum number of lights that can be used, the number of non-focus objects in the level, and the focus objects computed. Additionally, ALVA creates several background areas by dividing the background into several pieces and allocating an area for each piece. Allocating and dividing these areas is done in the same manner as ELE.

Once these areas are allocated, like ELE, ALVA uses a greedy algorithm to merge areas that are sufficiently near one another, thus enhancing performance by decreasing the number of areas that need to be lit. The algorithm is as follows:

```
Repeat
    For each area $a$
        if $\exists\, a'$ s.t. $|a - a'| < \varepsilon$, and both are focus areas with same importance (or non-focus) then merge $a$, $a'$
```

It then allocates some lights to each area. Once lights are allocated, ALVA assigns angles and colors to each light such that visual foci are established and visual continuity is maintained. Since colors impact visual attention, we will discuss colors here. Readers can assume angles to be set to 45° azimuth and 45° elevation relative to characters' faces, which are good angles for establishing visibility and character modeling as defined by [25]. It should be noted that the process of allocating light areas, angles, and colors occur on each event, including change of camera angle, change of location of an object, on entrance of a level, etc.

B. *Colors*

Color is a complex phenomenon that has been studied by psychologists, psychophysicists, vision, and visual designers [1, 26, 27]. Color affects attention and emotions [1, 2, 27]. Research identified several features of color that play a significant role in affecting attention, such as contrast, warmth, and brightness.

To use these features, we need to first define the attributes of color and develop formulae for defining these attributes in terms of RGB values. We define the attributes of color that are of interest as: ***brightness***, ***warmth***, and ***saturation***. We calculate lightness instead of brightness. Lightness and Saturation is calculated by transforming the RGB color to the HSL color space. We used the following formulae to determine lightness (l) and saturation (s) based on HSL color model [28]:

$$l = \frac{1}{2}[\max + \min] \qquad \text{(Eq. 1)}$$

$$s = \left\{ \begin{array}{cc} 0 & if\ \max = \min \\ \dfrac{\max - \min}{\max + \min} & if l \le \dfrac{1}{2} \\ \dfrac{\max - \min}{2 - (\max + \min)} & if l > \dfrac{1}{2} \end{array} \right\} \qquad \text{(Eq. 2)}$$

***Warmth*, **on the other hand**,** is an elusive quality. It impacts our attention, as discussed by Block and Treisman [1, 29]. Warm colors are defined to be colors with high proportion of reds and greens [27], while cold colors are colors with high proportion of blues relative to the reds and greens [27].

Several psychology and psychophysics theories describe warm and cool colors. However, none of them presented data that can be used to formulate warmth and coolness of colors in terms of the HSI or RGB color models. The best effort to measure this elusive quality is described in an unpublished paper by Katra and Wooten. They gathered results from several experiments in which subjects rated colors on a scale of –5 to 5, where 5 is warm and –5 is cold. The stimuli were controlled for hue and saturation [30].

Based on their results, we used a multiple linear regression method to formulate an equation describing color warmth, described in RGB color space. The formula is as follows:

$$warmth\left(\begin{bmatrix} R \\ G \\ B \end{bmatrix}\right) = \begin{bmatrix} 0.008 \\ 0.0006 \\ -0.0105 \end{bmatrix}^T \begin{bmatrix} R \\ G \\ B \end{bmatrix} - k \qquad \text{(Eq. 3)}$$

where k is a constant.

Another important concept that is constantly used by ALVA is contrast. Film and theatre lighting designers differentiate between three different types of contrast: lightness, warmth, and saturation contrast [1]. Contrast is measured as the difference between the lightness, warmth, or saturation of lights lighting the focus areas compared to lights lighting the surrounding areas. We use the same formulation used by ELE to measure contrast:

$$\text{contrast}_{\phi}(c) = \sum_{i \neq focus} \left| \phi(c_{focus}) - \phi(c_i) \right|, \qquad \text{(Eq. 4)}$$

where ϕ represents either lightness, warmth, or saturation.

C. *Contrast and Balance*

ALVA first assigns colors to each light in the level in a similar fashion to ELE, where constraint-based optimization is used to choose best colors for all lights in the scene to accommodate artists' constraints based on aesthetic color choices, mood, and depth. Once this is done, ALVA then revises the color assignments based on visual attention, as shown in figure 1. Thus, the assignment of color happens in two phases. This was done to simplify the equations involved for constraint optimization and provide modularity.

ALVA revises the color assignments based on visual attention. Research showed that our attention is directed towards warmer colored objects when they are surrounded by cool colored objects, but the impact may not be the same if a warm colored object is surrounded by objects whose color projects the same degree of warmth. Thus, contrast is key to modulating and adapting visual focus.

Following this theory, ALVA embeds several rules to manipulate colors of lights on the objects. These rules fall into several cases: level entry, changes in positions within the level, and during an event that stimulates a lighting change.

It is important to differentiate between these cases because the constraints imposed on lighting changes are different for each case. For example, upon an entry of a level, there are no constraints on lighting changes with regards to visual continuity. This is because the player has never seen the level before and so it is ok to perform any kind of edits. During play within the level, lighting should incur very little changes, especially overall level lighting due to the desirability to maintain visual continuity. If there is a lighting motivation, i.e. there is an event that causes lighting change then the system has freedom to change the lighting connected to the event.

For each case, ALVA looks at different sub cases that fall into the following criteria:

- Case a. the surrounding objects and background are too warm and too bright
- Case b. the surrounding objects and background are cold but bright
- Case c. the surrounding objects and background are too warm but not bright

For each of these sub cases, it develops a solution based on the case and the sub case. An example is as follows.

Let's consider *Case 1: upon entrance of a level*. In this case, since the participant has not yet seen the level, ALVA has freedom to change the colors of all the lights lighting the level and the objects. Calculations happen during level loading. ALVA consults the lights and texture color values in opposition to the lights on the object(s) and their importance.

Case a: condition:

Warmness (c) > threshold k

and brightness (c) > threshold l

action:

1. lessen brightness (c) and lessen warmness (c)
2. choose colors for object, c_i, to be warm and bright, such that the $\text{contrast}_{\text{lightness}}(c)$ and $\text{contrast}_{\text{warm}}(c)$ value is equal to its importance

where c is the average color on the areas surrounding the focus, i.e. non-focus, and background as well as other focus areas other than one surrounding b. c_i is color of light on focus area of object i.

As discussed above, ALVA does not run this routine every frame, but rather on every event or movement. This decision was made to optimize. Currently, ALVA runs at 20 frames/sec. This is slower than the required 30 frames/sec., but there is no noticeable lag.

V. EXPERIMENT DESIGN

To measure visual attention within a 3D game and compare the use of lighting for visual attention, we designed two experiments where we asked several students to play a game we developed as a mod for the popular first person shooter game: *Unreal*

Tournament 2003. We asked them to play two games: (1) the game modification we developed with static lighting and (2) the same game modification but with ALVA dynamically adapting the lighting for best visual attention. The order by which the games were introduced was chosen randomly to balance the order effect.

We asked participants to wear an eye tracker. We recorded their eye movements superimposed on the game video for later analysis. We also observed and analyzed their behaviors to determine points of frustration and engagement. At the end of each session, we interviewed them to gauge their experience and engagement.

We chose *Unreal Tournament* for several reasons. First, it is a complex fast paced 3D environment, where users are forced to decipher the environment quickly to respond to enemy attacks. Second, we can easily augment our intelligent lighting algorithms to the current game. Thus, it can be used for a comparative study, comparing results using current lighting methods vs. our proposed lighting system.

A. *Participants*

We asked 26 students from a 300-level undergraduate class at Penn State University to participate in the experiment for extra credit. From the 26 only 16 were usable due to problems with the eye tracker data. Ten of the 26 subjects wore contact lenses, or had dark eye colors or dark eye lashes, which caused calibration problems. From the 16 students, 13 students identified themselves as non FPS (First Person Shooter) gamers: 3 non-gamers and 10 casual games, while 3 identified themselves as FPS gamers.

B. *Procedure*

We asked the students to sign up for a 30-minute session. The experimenter introduced the procedure. We then asked them to wear a head-mounted eye tracker to track their gaze locations. For this experiment, we used ISCN ETL-500 eye tracker. The experimenter asked them to play *Soul Calibur II* on the Play Station for 10 minutes. During this time he calibrated the eye tracker. Also, this 10-minute session was used to get them acquainted with wearing the eye tracker while playing.

After this 10-minute session, we asked them to play the two Unreal Tournament games, for 10 minutes each. The game developed for this experiment is a modification for the Unreal Tournament 2003. The game was composed of 7 different environments (levels). The objective was to get to the exit going through all 7 environments without dying. We asked them to play the game for 7-10 minutes. If they die, they were asked to restart the game. A normal play through the game took an average FPS gamer 7 minutes to complete. We asked them to play the two different versions of the game for ten minutes each: one with ALVA and the other with static lighting. Figure 2 shows two screenshots from a level within the game; screenshot shown in figure 2(right) shows the level with ALVA while figure 2(left) shows the same point in the level but without ALVA. No specific treatments were made for the lighting embedded in the enemy textures. Figure 3 shows several shots in the game, showing with AVLA making different choices of light color and brightness to attract participant's attention by bringing the characters out.

Figure 2. Two screenshots comparing the system with and without ALVA emphasizing visual attention

While playing the game, we asked participants to shout when they see an enemy. The order of which version of the game they played first was randomized to minimize the order bias effect. After each session, we briefly interviewed them asking them to reflect on their experience playing the game.

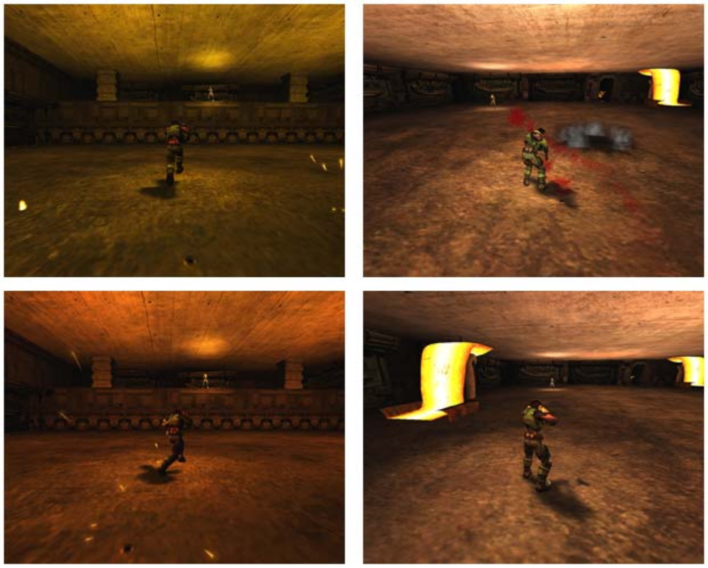

Figure 3. Screenshots showing different lighting treatments adopted by ALVA depending on lighting conditions to emphasize visual attention

During the play sessions, two researchers took observational notes identifying points of frustration, engagement, searching and environment scanning moments, and enemy misses. We also recorded their game play sessions; the video recorded showed their eye movements as a white cursor superimposed on the actual game play video. We used a counter to keep track of simulation time, measured in *ct* (counter time) rather than in seconds. We noted every time the user shouted that he/she spotted an enemy. We noted places when subjects did not remember to shout, and were reminded to do so.

Using this video we were able to analyze the time, in terms of simulation counter time, it took them to spot an enemy given the time the enemy appeared and the time they shouted that they spotted him. In analyzing the taped and observed interaction, we noted all enemy clear misses, where participants visually scanned the environment and missed the enemy even though he/she was not hidden in the shadows or behind obstacles. We also noted the number of times the player was killed during the play session.

C. *Results from static lighting version*

From our recorded video and observation notes, we deduced that the spotting time for novice users (users who identified themselves as non-first person shooter gamers) is significantly higher than that of expert users (first person shooter gamers). We calculated the time as an average of 8 *ct* for gamers and an average of 38 *ct* for casual gamers. For non-gamers it was harder to quantify the spotting time due to the fact that most of the time they did not spot an enemy before they were killed. Please note that the numbers above were deduced manually and may not be accurate figures due to the eye tracker time lags, time it took us to confirm a spotting event, and the movement of the player. However, since the same procedure was done on data collected from gamers as well as non-gamers, we deduce that the difference presented is valid.

The number of times players died before reaching the end of the level varied. FPS gamers' death times ranged 0-1, where two gamers achieved the objective in 7 minutes with no death and one achieved the objective in 10 minutes with one death. Deaths for casual gamers varied widely from 2 to 8, with only 4 of them completing the level within the allotted 10 minutes. None of the three non-gamers completed the level; the number of deaths ranged from 8 to 10, one quit before the 10 minute time slot has ended.

An example interaction proceeded as follows. A user enters a room, scans the environment for any visible enemies. Even though enemies exist, the user does not see them. The user advances into the room, hears gun shots, starts shooting everywhere while scanning the environment again, spotting nothing. The user looks at his health, notices that his health is dropping. He starts scanning the environment again, but by the time he actually sees the enemy, he is dead.

Later interviews with the players also showed differences between FPS gamers, non-gamers, and casual gamers. FPS gamers were able to spend more time within the environment and all of them reached the winning condition. They all expressed several changes to make to the levels for better game play, such as bigger guns, more rewards, etc. Casual gamers had mixed feelings. For example, one said the game was good but they were not FPS gamers so they would not be able to judge, while another said it was great, but he wanted more time to play the game. Non-gamers felt frustrated and did not appear enthusiastic with the game or environment.

D. *Implications from Static lighting version*

These results are significant for many interactive applications. The results show that in complex 3D environments non-gamers, more so than casual gamers, were not able to spot important characters quickly enough to respond, and thus ended up frustrated most of the time. Spotting time is necessary for many applications where users exhibit a visual search behavior, e.g. searching for an object, to complete a particular goal in the virtual environment.

It should be noted that the number of subjects is limited, and thus no real conclusive results are discussed here. Instead, the paper compares these results to results collected using the same procedure but with a dynamic lighting approach that takes into account visual attention. By discussing these comparative results and showing some simple measures of significance, we suggest the utility of a dynamic lighting approach that takes visual attention into account.

E. *Results from ALVA version*

By analyzing the observed and videotaped responses, we deduced that non-gamers and casual gamers were able to spot the enemy faster with the dynamic lighting system than without it, and thus were able to survive longer (see figure 4). We also found that the spotting time of gamers was also slightly improved. We calculated the time as: average 4 *ct* for gamers, average 26 *ct* for casual gamers, and 46 *ct* for non-gamers. The biggest difference we could deduce right away was that non-gamers did not die as much as in the version without ALVA, and one out of the three completed the game. As noted above, the numbers were deduced manually and may not be accurate due to the eye tracker time lags, time it took us to confirm a spotting event, and the movement of the player.

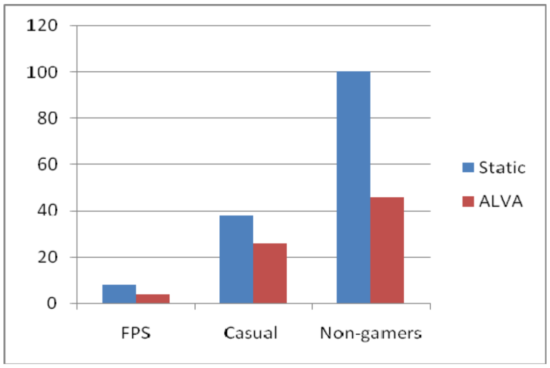

Figure 4. Difference in counter time of spotting times between FPS gamers, Casual gamers, and Non-gamers.

We ran a t-test analysis on this data comparing each group and deducing significance. Results are shown in table 1. As it can be seen, for FPS gamers, their spotting counter time did not show any significance with or without ALVA. But for casual gamers and even more for non-gamers, the results of spotting time show significant improvement with ALVA than without. This leads us to conclude that the introduction of ALVA significantly improved the enemy spotting time of casual gamers and non-gamers. It should be noted, however, that the number of participants are low to draw any conclusive evidence. However, it is still worthwhile to note these results and variance to show the success of the method and suggest an opportunity for further exploration.

Table 1. T-Test Analysis on results of counter time of spotting

	Mean	Stdev	T-Test	Significance
FPS gamers-Static	8	2.65	2.449	95% confidence, no statistical significance
FPS gamers-ALVA	4	1		
Casual gamers-Static	38	13.17	2.2832	95% confidence, statistically significant
Casual gamers-ALVA	28	10.14		
Non-gamers-Static	100	0	15.59	95% confidence, statistically significant
Non-gamers-ALVA	46	6		

The number of times players died before reaching the end of the level varied. In comparison with the static lighting approach, the number of deaths for casual gamers and non-gamers was considerably less, see figure 5. The figure shows the max deaths that occurred over all categories, rather than average. As with the game with static lighting, gamers' death times was 0-1, where two gamers achieved the objective in 7 minutes with no death and one achieved the objective in 10 minutes with one death. For casual gamers death times varied from 2 to 6, with 6 of them completing the level within the allotted 10 minutes and 4 were unable to complete the level. One of the non-gamers completed the level; the number of deaths ranged from 4 to 6. None of the non-gamers quit before our imposed deadline of 10 minutes.

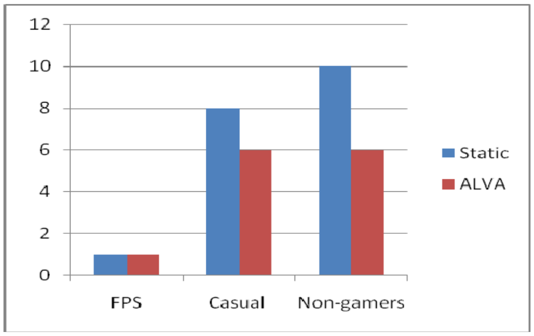

Figure 5. Difference in deaths times between FPS gamers, Casual gamers, and Non-gamers.

We also ran a t-test analysis on this data comparing each group and deducing significance. Results are shown in table 2. Similar to spotting time, the number of deaths of FPS gamers was not significantly different with the system with ALVA and the system without. However, for casual and non-gamers the results show statistical significance in the reduction of the number of deaths of these players when playing within the system with ALVA than the system without. This leads us to conclude that the introduction of ALVA significantly improved the number of deaths of casual gamers and non-gamers.

Table 2. T-Test Analysis on results of number of deaths

	Mean	**Stdev**	**T-Test**	**Significance**
FPS gamers-Static	0.33	0.58	0	95% confidence, no statistical significance
FPS gamers-ALVA	0.33	0.58		
Casual gamers-Static	6.7	2.214	2.6364	95% confidence, statistically significant
Casual gamers-ALVA	4.4	1.65		
Non-gamers-Static	9.33	1.15	4.914	95% confidence, statistically significant
Non-gamers-ALVA	5	1		

Interviews with players emphasized that gamers were ok with the game, non-gamers and casual gamers were happy with the game, but some expressed inability to react quickly enough to win. It should be noted that playing an FPS requires fast reflexes in addition to fast spotting times. Thus, these results are not surprising. However, helping non-gamers spot enemies faster achieved slightly better results and less overall frustration based on our observations.

F. *Implications from ALVA version*

The results suggest that dynamic lighting for visual focus can achieve better results for gamers, non-gamers, and casual gamers. We also showed these results and the system to two different design teams at two game companies, and asked for their feedback. Both teams were interested in using the lighting system within their production cycle, but wanted to test it in a more complex environment.

G.*Limitations of the Experiment*

There are a lot of limitations to the experiments discussed in this paper. We have encountered many issues with the data, including inability to use some data due to problems of tracking eyes with dark eye lashes and eye lids. Also, data collected from people wearing contacts was unusable.

Additionally, participants were asked to play the same game in session 1 and 2. While we changed the order to balance the order bias, we believe participants will still be a little better in the second round due to knowledge of the level (although enemies are unpredictable). In hindsight, we should have asked participants to come back in 2-3 days which would have minimized the learning between the two sessions.

Measuring spotting time is not an easy task. In our pilot studies, we used the eye tracker and identified a successful spot if the player's eye was focused on one position for a certain amount of time. This turned out to be inaccurate as revealed by our later interviews with the players. For this experiment, we decided to use shouting as a method for identifying when they spot an enemy. This did not work all the time because participants forgot to shout sometimes. In our analysis, we used a combination of both measures as well as observation notes to identify a successful spotting.

Although the experiments are limited in many ways, we still see the results as significant and sufficient to move forward with this research and look into the use and possible application for such a system.

VI. APPLICATIONS AND FUTURE WORK

ALVA and the results discussed here were demonstrated and discussed with several companies, such as Middway and Microsoft, to evaluate its use and situate its contribution. The results of these demonstrations were fairly positive. Several suggestions were made to enhance the experiment. These improvements included more participants, also analyzing all other data from the game log, including cursor movements, number of shots, etc.

There were also several suggestions on the applications of this system. Our original goal was to use this system to enhance games, like First Person shooters that are aimed at non-gamers or non-core First Person Shooters. We also were interested in using this system for serious games and training based games as well as adventure and action/adventure games. Several people suggested that this system can be used to train non-gamers by gradually removing the visual attention element from maximum to minimum. One designer, in particular, suggested using this system as a 'visual focus knob' for controlling game difficulty.

In the future, we aim to study these directions to establish possible uses. We plan to revise ALVA to target these uses and develop different experimental studies to evaluate the system's quality and use. We also aim to include more industry personnel in our evaluations in order to make a more conclusive contribution to the field. Furthermore, results from other studies we conducted to explore the difference in the visual attention process between game genre alluded to the existence of both top down and bottom up visual attention methods [31]. ALVA only included bottom-up visual attention. We would like to extend this model exploring top down visual attention.

VII. CONCLUSIONS

The goal of this paper was to present a dynamic lighting system called ALVA that dynamically adjusts lighting in real-time for better visual focus within game environments. To this end, we discussed ALVA's algorithms and rules in detail taking into consideration how it represents color and makes decisions to allocate different colors to different lights within the scene. We also discussed experimental results showing the success and advantage of using ALVA over a static lighting paradigm. These results show great promise for the success of the approach. Conversations with industry people also uncovered many other possibilities for embedding such a system within games. In the future, we hope to evolve this system and continue to evaluate its use and impact.

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