# Dynamic Light Amplification for Head Mounted Displays

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## Abstract

Two common limitations of modern Head Mounted Displays (HMD): the narrow field of view and limited dynamic range, call for rendering techniques that can circumvent or even take advantage of these factors. We describe a simple practical method of enhancing visual response from HMDs by using view-dependent control over lighting. One example is provided for simulating blinding lights in dark environments.

## 1 Introduction

Human eye has a very high dynamic contrast ratio, approximately one to million. Spatial resolution, across the visible field, on the contrary, is relatively low. We are able to see objects in sharp detail only if they fall on a very small area of the retina, called fovea, where most light photoreceptors are concentrated. Projected outwards into the viewable scene, this area is about the size of the full moon, or 15°. Everything outside of this high-acuity area is basically a blur.

Therefore, rendering for wearable displays must account for and, whenever possible, take advantage of these features of human vision, in order to circumvent the limitations of the current displays. In particular, low contrast and brightness of modern HMDs do not allow to reproduce the whole range of light intensities that the human eye can perceive. As a result, virtual scenes with wide range of luminance often look unconvincing in VR, which significantly affects the sense of presence.

We base our method on the idea that objects' appearance in immersive VR must be view dependent, as in real life. In the general case, this applies both to geometric representation and shading of the objects. In this work, we focus on improving lighting part of the rendering process, which provides a partial solution to the problem of limited brightness and contrast of available HMDs.

## 2 Small Fovea + Eye Movements = Narrow FOV + Head Rotations

Our approach is based on an observation that for non-panoramic HMDs, orientation of the user head approximates his or her gaze direction. Field of view (FOV) of most popular HMDs is relatively low, ranging between 40 and 60 degrees diagonally [Bungert 2006]. To compare, human visual field extends to 180° horizontally and 75° vertically. Limited field of view leads to a "tunnel vision" effect which is generally regarded as one of the most objectionable drawbacks of HMDs. However, this disadvantage becomes a very helpful feature, for tasks that require estimation of the user gaze direction. Furthermore, the tunnel vision effect prompts viewers to turn their heads more actively, in order to see the scene outside of the visible HMD frame. As a result, fast eye movements, that happen in real life, are replaced by relatively slow head rotations in VR, that can be reliably tracked by a variety of available devices and used for rendering purposes.

## 3 Dynamic Light Amplification Algorithm

On each cycle of the main graphics loop, each light source is checked against the current user position and orientation. If the light source appears to be in the high-acuity area of the user's gaze (approximated by the head direction, as described above), the intensity of the light source is artificially magnified to meet the higher eye sensitivity in this area.

For different types of lights, magnification factors are computed differently. For positional lights, this factor is inversely proportional to the distance from the position of the light source to the center of the viewing plane. For directional lights and spotlights, the direction of the light must also be taken into account: if the camera and the light source are oriented towards each other, the light becomes brighter.

```
for all active light source $L$ do
    $factor \leftarrow$
        $-L.direction \bullet cam.direction$,
        for directional light;

        $1/$distance_to_screen_center($L.pos$),
        for positional light;

        $1/$distance_to_screen_center($L.pos$)$-$
        $L.direction \bullet cam.direction$,
        for spot light.
    $L.intensity \leftarrow L.intensity * factor$
end for
```

**Figure 1:** *Summary of the view-dependent lighting control. The values returned by dot product* $\bullet$ *are clamped to* $[0;1]$ *range. Evaluating distance to screen center requires transformation of light position from world to camera space. An alternative way of computing distance factor is shown in Figure 2.*

## 4 Implementation

The light amplification algorithm was implemented in open-source 3D visualization system Flatland [2002]. Flatland utilizes OpenGL graphics API and provides stereoscopic rendering for both active and passive stereo configurations. In our system, both types of displays were used: Virtual Research V8 HMD (640 x 480 pixels, 60° FOV, passive) and 5DT800 HMD (800 x 600 pixels, 40° FOV, active). For motion tracking, Flock of Birds by Ascension was used, running in 9 feet extended tracking range.

In Flatland, each light source is a node in the scene graph, with its own $update()$ function. These functions are executed in the main graphics loop, after updating all scene transformations and before lighting is applied. During $update()$, each light source inquires the

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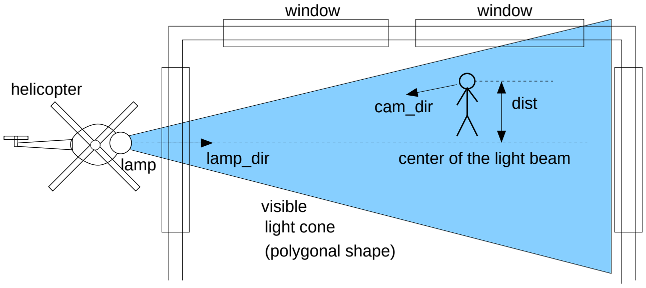

```
1: procedure HelicopterLightUpdate($cam$, $lamp$)
2: $dist \leftarrow$ distance from $cam$ position to
       the $lamp$ light beam line
3: $D \leftarrow \begin{cases} 1 & \text{if } dist < dist_{min}; \\ 0 & \text{if } dist > dist_{max}; \\ \text{falls off linearly} & \text{otherwise.} \end{cases}$
4: $A \leftarrow -lamp.direction \bullet cam.direction$
5: $lamp.intensity \leftarrow c_0 + c_1 D + c_2 A$
6: end procedure
```

**Figure 2:** *A scene layout and* $update()$ *function of the helicopter lamp. The light intensity is modified according to the relative position and orientation of the light with respect to the viewer. Rendered results are shown in Figure 3. Notes. Line 3, calculating distance factor* $D$*: constants* $dist_{min}$ *and* $dist_{max}$ *were set at 1 and 10 meters, respectively. Line 4: Angle factor* $A$ *falls off as a cosine. Line 5:* $c_0$, $c_1$, $c_2$ *are user-defined parameters, useful values are 5, 5, 6.*

system for the current position and orientation of the camera and adjusts its intensity accordingly.

If a light source is attached to an object with visible geometry, calculations of light amplification factors must also account for additional light that comes from that object. For example, a spotlight may be placed at the apex of a semi-transparent polygonal cone, which will make the light beam visible, as shown in a diagram in Figure 2. In this scene, a very bright spotlight is attached to a helicopter that flies around a building, “looking” into windows. When the light beam hits the viewer’s gaze, the intensity of the light source is magnified, creating the blinding effect, see Figure 3. This VR system was developed for training first responders in hostile environments [Vincent et al. 2008]. The helicopter object with a blinding light was modeled and programmed to add a sense of drama to training scenarios.

The light amplification algorithm, described above, is not intended to simulate how human eye reacts to extreme light. These adaptation processes are rather complex, including fast optical adjustments (pupil dilation, which happens in seconds) and slow changes in retina’s chemistry that take minutes. We used a more pragmatical approach, based on the similarity between the tunnel vision of common HMDs and a small size of high-acuity vision of a human eye. From that perspective, many problems of improving lighting for HMD rendering have simple geometric solutions, that can be easily programmed for most VR systems and applications.

## 5 Conclusions

We described a simple yet effective method of enhancing rendering of virtual scenes under extreme lighting conditions. This method does not require additional data structures; it does not need pre- or post-processing steps. If fits well within OpenGL-style lighting frameworks and can be easily integrated into most existing rendering systems.

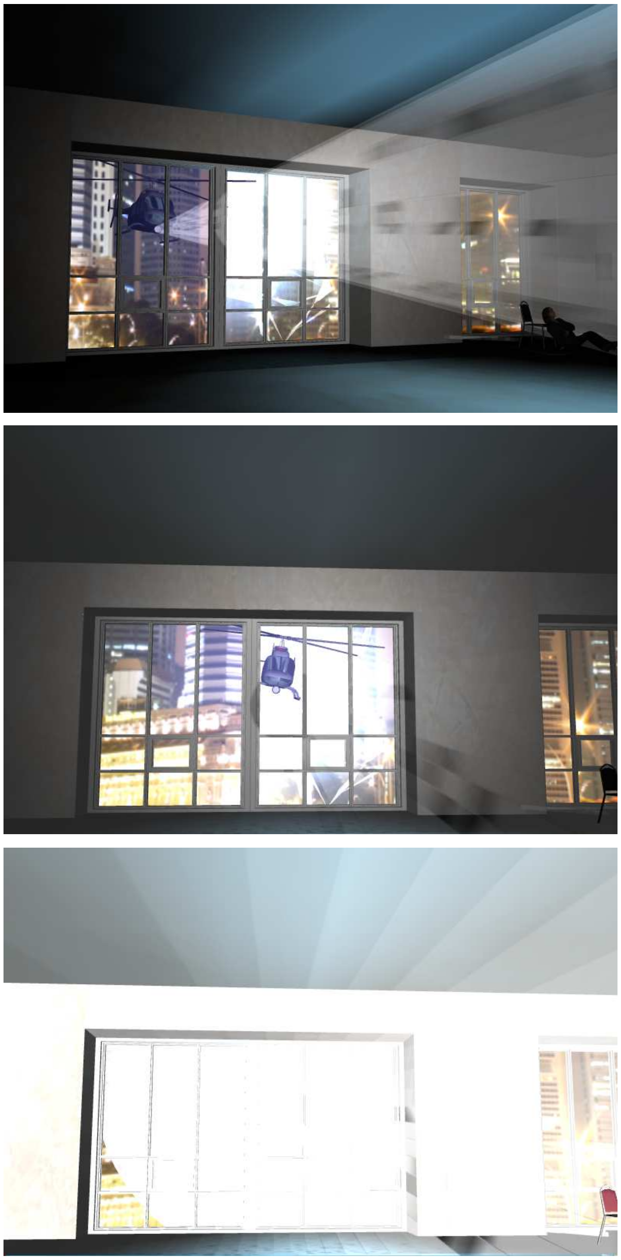

**Figure 3:** *“Blinded by the virtual light”. When the light points away from camera, lighting with standard OpenGL spotlight produces acceptable result (top). When the light points directly into the camera, standard lighting looks unnaturally flat (middle). Dynamic light amplification creates the desired blinding effect (bottom).*

## References

BUNGERT, C. 2006. *HMD/headset/VR-helmet Comparison Chart*. http://www.stereo3d.com/hmd.htm, updated on Dec. 27, 2006.

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