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Occlusion culling techniques for layer-based computer-generated holography

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Abstract: Three occlusion processing techniques for computer-generated holography are proposed to support layer-based methods of acquiring holograms from point clouds. The techniques use Gaussian masks and masks generated by dilation per point or per layer. © 2018 The Author(s)

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1. Introduction
Computer-generated holography is a technique to acquire holograms by simulating the diffraction and interference phenomena that happen during light propagation. The interference patterns of computer-generated holograms (CGHs) are calculated by superimposing complex amplitudes emitted from the object points. A high-end CGH should take into account occlusions in the recorded scene; however, occlusion handling is a challenge in digital holography. Although several occlusion handling methods have been suggested in holography, occlusions for point clouds have not been extensively investigated. Recent approaches include a method with spatial frequency indexing [1] and light shielding integrated in hybrid layer-based CGH method [2].

In prior work [3], we have introduced an occlusion technique that utilizes inverse Gaussian filters to mask occluded points in the context of the fast CGH method proposed. The method uses multiple wavefront recording planes (WRPs) and exploits an intra- and inter-WRP light propagation scheme that deploys angular spectrum propagation. The technique reduces the computational complexity by using pre-computed look-up tables. The contribution of the points is calculated from the point the furthest from the hologram plane to the closest, enabling the occlusion processing techniques discussed here. Occlusion handling is processed by masking the field contributions from the previously calculated points, which are located behind the currently processed point, with inverse Gaussian distribution profiles. We compare the aforementioned technique with two variations for occlusion processing, suitable for layer-based approaches, such as the WRP method. The three methods are presented and compared in a quantitative and qualitative manner, based on the experimental results presented, while summarising conclusions end the manuscript.

2. Occlusion processing methods
The methods presented here aim to occlude the light emanating from points that are situated behind each point, and therefore suppress their contribution to the optical field recorded at the WRPs and by extension at the hologram plane.

1. Inverse Gaussian masks applied per point: In this technique the optical field recorded in this area is suppressed by multiplying the field locally – around the area of its orthogonal projection to the plane, with the complement of a Gaussian distribution. This happens before adding the contribution of each point to the WRP. The size of this occlusion mask is calculated based on the lateral density of the point cloud i.e. the mean distance between two points when projected in the hologram plane – such that two points of the same depth level do not overlap and occlude each other.

2. Inverse Gaussian masks applied per point per WRP: This technique is identical to the previous with one difference: The occlusion masking per point is applied per point for all the points that belong to a WRP and then the contributions of the points in this WRP zone are added sequentially.

3. Binary masks applied per WRP: In this case, the orthogonal projection of all the points that belong to a WRP form a binary mask, whose shapes are expanded by applying the dilation morphological operator. This mask is filtered with a Gaussian filter so that the occlusion is applied smoothly in the area around each point. This mask is applied by multiplying it with the optical field containing the contributions of the points behind the points of this WRP. Subsequently, the contributions of the points in this WRP zone are added sequentially.

The pseudo code below shows the differences between the three techniques.
3. Experimental results

To compare the proposed occlusion processing techniques we generated CGHs from the point cloud dataset "Perforated ball" (218,640 points). The resolution of the CGHs is 2,048-by-2,048 pixels, the pixel pitch is 4\(\mu\)m, the wavelength of the reference beam is 633 nm and the object is considered at a distance of 60 mm from the hologram plane. Figure 1 shows the numerical reconstructions from the 4 CGHs. Table 1 shows the computation time required for the calculation of the CGHs and for each occlusion processing technique. The simulations ran in MATLAB code on a computer with a 3.30 GHz Intel Core i7-5820K CPU processor and Windows 8.1 (x64) as operating system.

![Fig. 1. Numerical reconstruction of the hologram "Perforated ball" generated (a) without occlusion processing and with occlusion processing that exploits (b) Gaussian masks per point (c) Gaussian masks per WRP (d) binary masks generated by dilation per WRP.](image)

### Table 1. Comparative results for the computation time for full CGH computation and for the occlusion processing techniques for the hologram "Perforated ball"

<table>
<thead>
<tr>
<th>Technique</th>
<th>CGH [sec]</th>
<th>Occlusion only [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No occlusion processing</td>
<td>46.3</td>
<td>-</td>
</tr>
<tr>
<td>Gaussian mask per point</td>
<td>50.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Gaussian mask per WRP</td>
<td>47.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Dilation mask per WRP</td>
<td>57.1</td>
<td>10.7</td>
</tr>
</tbody>
</table>

4. Conclusions

In this work, we have compared three occlusion methods regarding their computational complexity and quality of the reconstruction. The results show that the first method proposed has the best result visually, providing better depth cues, thus higher 3D perception, while the complexity is higher due to the fact that the process has to be applied sequentially per point. The second and third approaches have the disadvantage that the depth difference of points that belong to the same WRP is not taken into account, resulting in worse depth separation. However, for scenes with increased depth, thereby higher number of WRPs they can be more efficient – especially for high resolution holograms, where block based approaches could be deployed. Additionally, they have the important advantage of enabling parallel computation, thereby faster CGH calculation in a GPU implementation environment.

References