Real-time Underwater Caustics for Mixed Reality 360° Videos

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Introduction

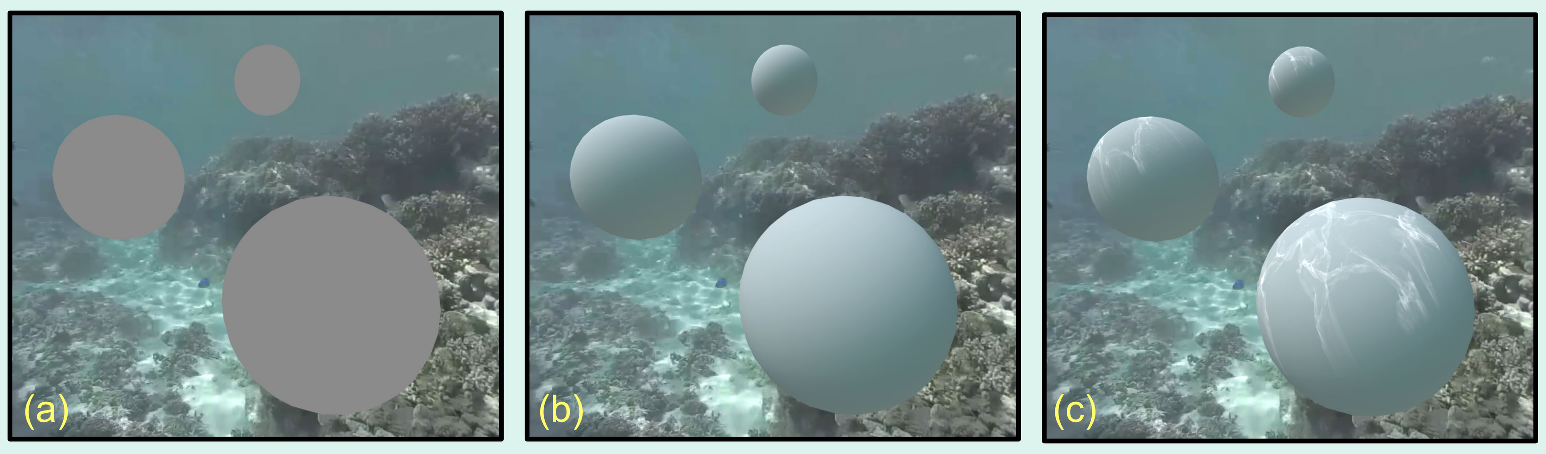

Figure 1. Comparisons, from the left: flat ambient light, previous lighting methods [1,2], and our lighting method.

Existing work [1,2] enables real-time composition of virtual objects into 360-video while achieving high visual quality, but does not address underwater lighting effects (Figure 1, (a) and (b)). One such lighting effect is caustics, the patterns of light created when light refracts through the water surface. We present a novel method to enhance the visual quality of underwater mixed reality (MR) in 360-video with blended underwater caustics (Figure 1, (c)). Our main contributions are summarized as follows:

- We developed a novel method for real-time caustics suitable for underwater MR rendering into 360-video viewed at high frame rates (over 120FPS per eye) on modern HMDs.
- We integrated an interface into the Unity game engine to blend virtual objects and water caustics into underwater 360-video semi-automatically.

Lighting and Composition

We use previous work to simulate ambient lighting with image based lighting (IBL) [1] and detect light sources in the video [2] to provide high frequency lighting. We adapt and enhance this setup for underwater MR with caustics as follows:

- We assume the main light source underwater is the sun and is located in the top hemisphere of the video.
- We apply inverse tone mapping required for IBL to only the top half of the video to reduce flickering in the IBL caused by caustics on the ocean floor becoming over exposed.

Real-time Underwater Caustics

Rendering caustics requires a surface to scatter the light for generating the caustic patterns. We simulate and render a water surface to a normal map, using Gerstner waves [3] for large waves and scrolling normal maps for small waves. We make the normal map repeat seamlessly by cropping it to 90%, wrapping the cropped parts to the opposite side and blending with linear interpolation (Figure 2).

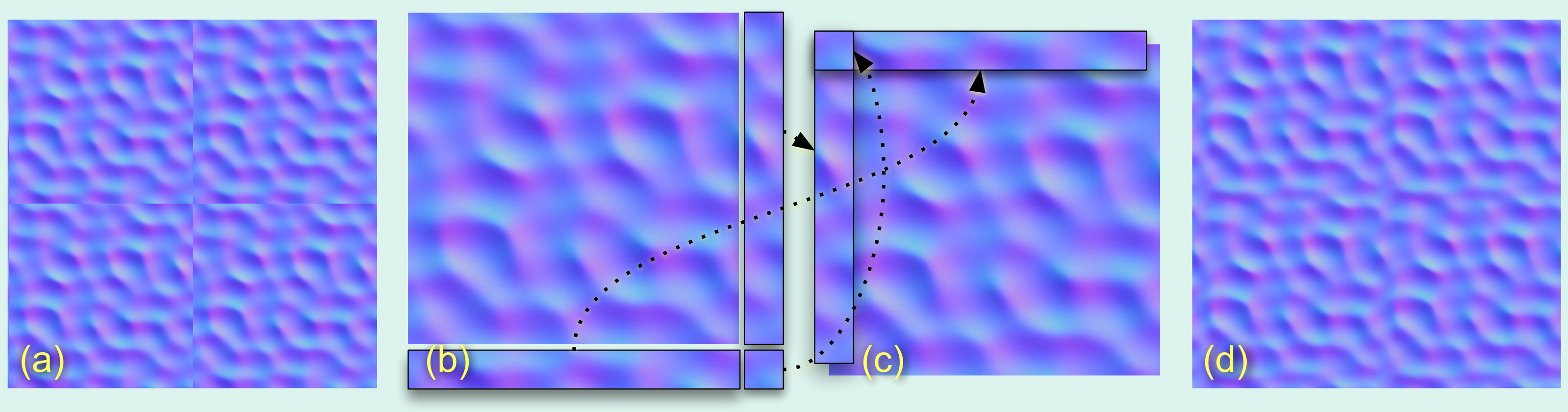

Figure 2. Water surface made seamless: (a) original water surface, (b) 10% cut from bottom/right, (c) 10% blended into top/left, (d) seamless water surface.

Caustics are rendered with a caustic map [4] using an adaption of the caustic triangle method [5] to update it in real-time. We project and refract a subdivided plane through the water surface onto a plane and additively blend overlapping triangles. We calculate the intensity per pixel by creating a triangle fan around each pixel and averaging the ratio between the area before the triangles are projected and after (Figure 3). We also refract the detected light direction through a plane to approximate the sun direction above the water surface, which we use when projecting the plane to get a closer match with the 360-video.

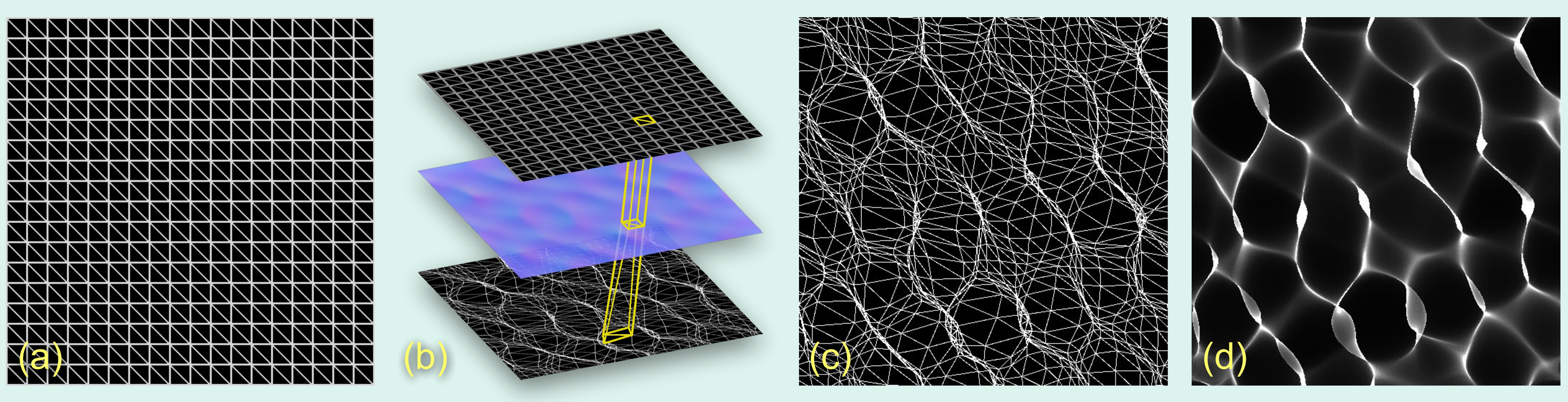

Figure 3. Caustic map generation: We create a subdivided plane (a) and project the vertices through the water surface (b). From the projected plane (c) we calculate the intensity per pixel to create the final caustic map (d).

Caustics are rendered by multiplying the caustic map with the detected light color and projecting it onto the virtual objects, using the detected light direction to determine the uv coordinates.

Results

We tested the performance on a computer using an Nvidia GeForce GTX 1070 graphics card, Intel Xeon Processor E5-1607 v2 with a 3GHz clock speed and 16GB ram. Generating the 64x32 resolution textures required for IBL and caustic map took 0.2ms and 0.3ms respectively. Rendering the final image only requires texture look-ups for light calculations and is able to achieve less than 5ms rendering time for scenes using a 4k video and containing 20 3D models with 14k triangles each.

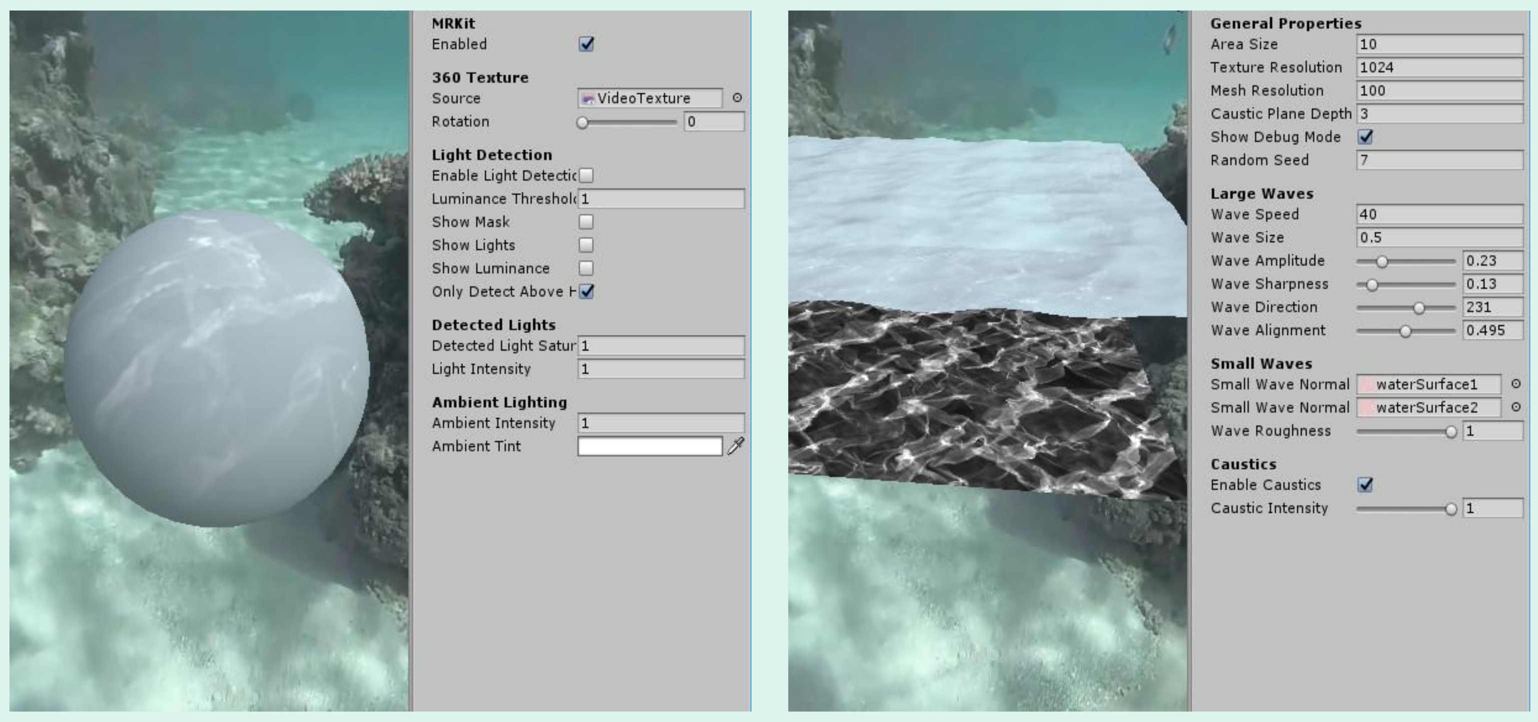

Figure 4. Interface for tuning the light and caustics parameters.

The parameters of our interface are separated in two: The general lighting and composition (Figure 4, left), and caustics (Figure 4, right). For easy user control, we provide a set of parameters to control the Gerstner waves. The water surface and corresponding caustic map is viewed through the game engine's scene view, making it easier to match with the 360-video. Users can produce a variety of caustics to match the 360-video (Figure 5).

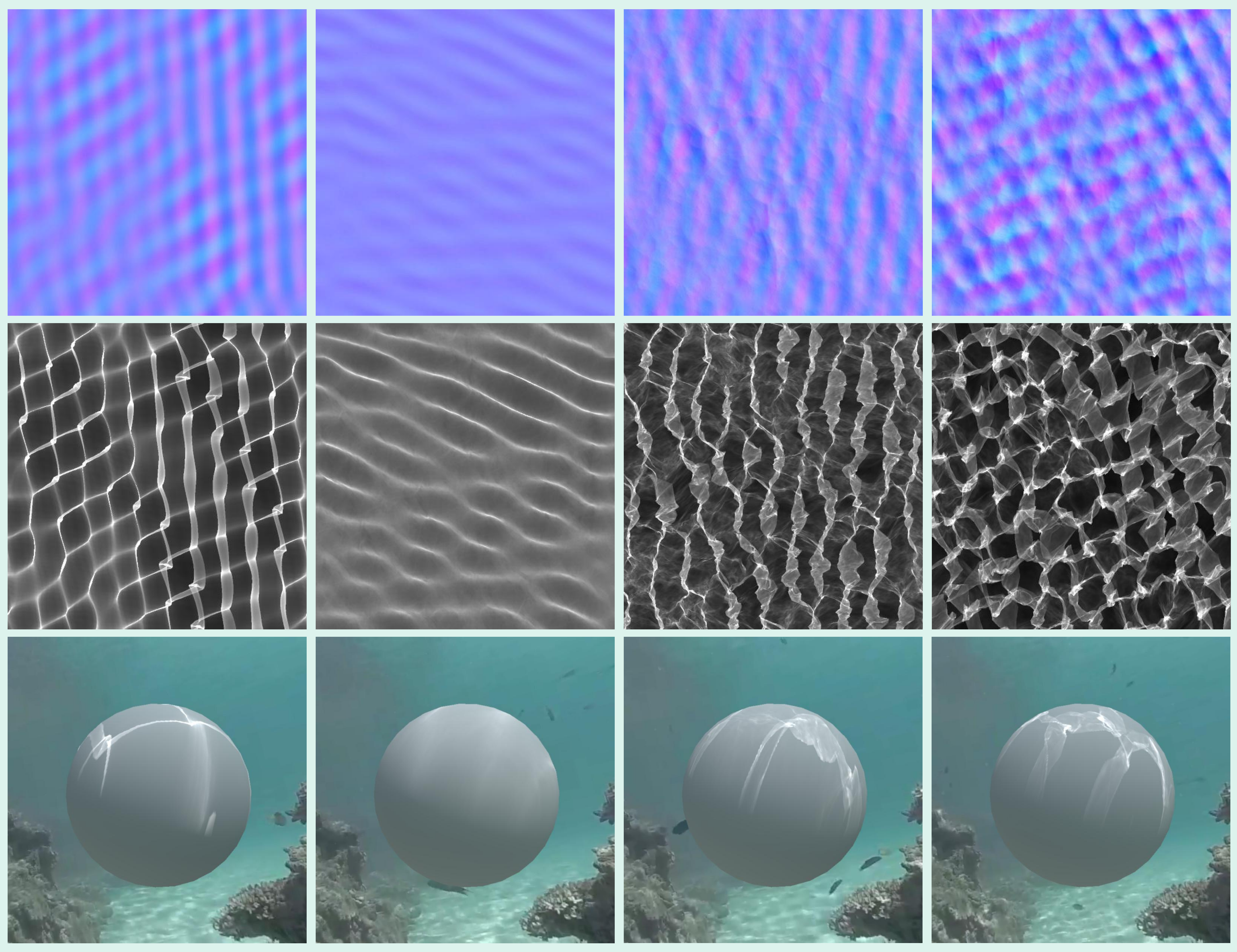

Figure 5. Water surface normal maps with corresponding caustic maps and virtual objects rendered with caustics.

Conclusion

We present a novel method to illuminate and blend virtual objects into 360-video with real-time underwater caustics. However, there are a few limitations to be improved in future work:

- We assume a single directional light (sun). Positional lights, such as torches held by nearby divers, could be addressed by including depth and light position detection.
- Other underwater effects, such as fog and god rays, could be considered for improving overall blending.

References

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