HySAR: Hybrid Material Rendering by an Optical See-Through Head-Mounted Display with Spatial Augmented Reality Projection

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ABSTRACT

We propose a hybrid SAR concept combining a projector and Optical See-Through Head-Mounted Displays (OST-HMD). Our proposed hybrid SAR system utilizes OST-HMD as extra rendering layer to render a view-dependent property in OST-HMDs according to the viewer's viewpoint. Combined with view-independent components created by a static projector, the viewer can see richer material contents. Unlike conventional SAR systems, our system theoretically allows unlimited number of viewers seeing enhanced contents in the same space while keeping the existing SAR experiences. Furthermore, the system enhances the total dynamic range, the maximum intensity, and the resolution of perceived materials. With a proof-of-concept system that consists of a projector and an OST-HMD, we qualitatively demonstrate that our system successfully create hybrid rendering on a hemisphere object from five horizontal viewpoints. Our quantitative evaluation also shows that our system increases dynamic range by 2.1 times and the maximum intensity by 1.9 times compared to an ordinary SAR system.

Keywords: Optical see-through displays, hybrid material rendering, spatial augmented reality

1 INTRODUCTION

Spatial Augmented Reality (SAR), or projection mapping, has been pursuing the reality of material rendering. Several researches have utilized SAR to achieve more realistic material rendering on physical surfaces. The main approach uses multi projector-camera installation to achieve higher resolution [1] and dynamic range [7]. Although these researches achieve attractive texture appearances on physical surfaces, the resulting appearances are valid for only a single viewpoint. To display the specular component that is dependent on a viewer's viewpoint in common SAR, the projector would need to render several images to each viewers. Although there are some SAR systems that render different images for each viewer by spatially [3, 4] or temporally multiplexing [5], it is not easy to increase the number of viewers without losing spatial or temporal resolution of SAR contents.

On the other hand, Optical See-Through Head-Mounted Display (OST-HMD) can render different images for individual users with built-in head-tracking system as typified by Microsoft HoloLens. There are some researches that combines projectors and OST-HMDs to enhance the appearance of virtual contents [2, 6]. While they mostly focus on enriching spatial rendering, they have not treated the combination of an OST-HMD and a projector as a hybrid rendering engine equipped with parallel rendering paths for improved material rendering of a single object.

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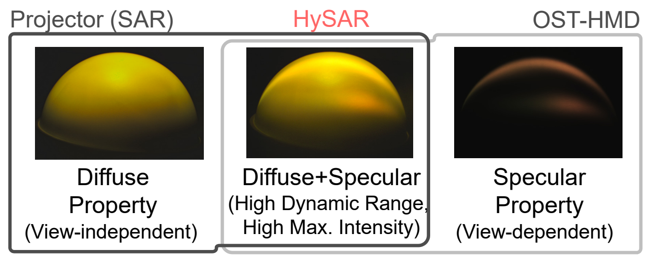


Figure 1: Summery of our HySAR concept.

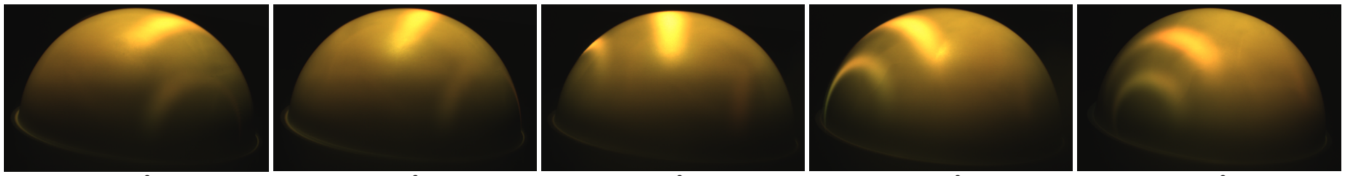
This work thereby proposes HySAR, a hybrid SAR system that combines an OST-HMD with a projector for better material rendering than ordinary SAR systems (Fig. 1). While shared view-independent (VI) components such as diffuse are rendered by a projector, the OST-HMD behaves as an extra rendering layer of SAR to display view-dependent (VD) components from viewpoints. As a result, we can scale the effective viewers without compromising the SAR quality by increasing the number of OST-HMDs. In addition, the system enhances the total dynamic range, the maximum intensity, and the resolution of perceived materials. Overall our proof-of-concept system successfully demonstrates hybrid rendering on a 3D hemisphere object with different viewpoints. Moreover, experimental results show the performance enhancement of HySAR over conventional SAR (spatial resolution: $\times 2.7$, maximum intensity: $\times 1.9$, dynamic range: $\times 2.1$).

2 HYBRID RENDERING

To achieve rich material expression, our system simulates surface materials of objects in accordance with Di-chromatic reflection model. The model is simplification method for shading. It assumes that the reflection components are the sum of the diffuse (VI) radiance R_d and the specular (VD) radiance R_s. When a projector casts an image on a diffused surface, we perceive the surface as a diffused color material. In this situation, our eyes only perceive the ambient radiance R_a and the diffuse radiance R_d. If multiple viewers wearing OST-HMD are dynamically changing their view directions, the OST-HMDs update and add the specular radiance R_s for each view direction in real-time. Conseqently, the system can simulate wider material expression for multiple viewers than conventional SAR.

3 TECHNICAL SETUP

Figure 3 shows the overall hardware setup. Our system combines Microsoft HoloLens as an OST-HMD with a ceiling-mounted wide-angle projector. We use the Unity 5 game engine for rendering both the projected CG content and the content displayed in the glasses. Both the projector and the OST-HMD are calibrated through Optitrack motion capture system. In the calibration for the projector, we estimate a 6 Degree-of-Freedom (6DoF) pose between the motion capture system and the projector through the Kinect v2 cameras. In the calibration for OST-HMD, we manually adjust the pose matrix between the motion capture system and HoloLens.



40° 20° 0° -20° -40°

Figure 2: Rendering results with different horizontal view angles. Each column shows a different viewpoint with the horizontal view angle shown.

Table 1: Measured resolution, maximum intensity, and dynamic range of HySAR, projector only (i.e., SAR), and OST-HMD only systems.

	HySAR	SAR	HMD	HySAR / SAR
Resolution [pixel/deg]	**61.5**	22.6	61.5	2.72
Maximum intensity	**5203**	2798	4844	1.86
Dynamic range	**143**	69	6	2.07

Figure 3: An overview of the hardware setup. (left) The SAR prop and HoloLens. The user-perspective camera installed behind the right optical element of the HoloLens. (right) The ceiling-mounted projector which displays a VI component on the prop.

4 Experiment

To evaluate our prototype, we prepared a diffusive white hemisphere for an SAR prop to evaluate the composition of the materials. In our experiments, the prop creates slight specular reflections because it was made of resin coated with white matte acrylic paint. To obtain images from viewpoints through the HoloLens, we installed a user-perspective camera placed behind the right optical element of the display. We used Ward model for specular models to evaluate rendering results. For rendering, we set three virtual light sources in simulation.

We compared rendering results with different horizontal view angles (-40°, -20°, 0°, 20°, 40°). From the results of the overlaid VD materials (Fig. 2), the virtual VD components are shifted corresponding to the viewpoints. As a result, our system enhances virtual material property, especially when the viewer is moving around the object.

To evaluate the difference of the rendering resolution between the OST-HMD and the projector, we calculated the number of pixel per view angle of the user-perspective camera. In our experimental setup, we could calculate the spatial resolution of both devices in the image plane: 22.6 [px/deg] in standard SAR and 61.5 [px/deg] in HySAR (Table 1). Considering that the critical gap size of standard human visual acuity is about 60 pixel per degree, the resolution of the VD component on the OST-HMD is comparable to 20/20 visual acuity. On top of this analysis, our system can theoretically present detailed material property around the specular component.

We measured the maximum intensities as well as the dynamic ranges of HySAR, common SAR and OST-HMD only systems, respectively. We captured the high dynamic range image using our linearized camera (same camera as the user-perspective camera) with multiple exposures. We measured these values in a dark environment for HySAR and SAR systems, while under an environment light for the OST-HMD only system. Table 1 shows the measured values. Note that the maximum intensity values represent relative intensity ratios with respect to the luminance of a physical object under environment lighting. As well, the dynamic range is computed as the ratio of the maximum intensity to the minimum intensity of each system. From the result, we confirmed that HySAR could display both the highest maximum intensity and the highest dynamic range than the others. In particular, its maximum intensity was almost 2.1 times higher than that of the projector only system; and its dynamic range was more than 24 times higher than OST-HMD only system.

5 Conclusion

We propose the hybrid material rendering by an OST-HMD with a SAR projection. By combining them, the hybrid system can render VD component corresponding to the unlimited number of viewer in real-time without interference. Moreover, the evaluation shows that the system achieves high-dynamic range and high resolution material expression, by easily installing the system in existing SAR applications. We are excited that researchers will explore the further possibility of the material rendering by combining an OST-HMD with an SAR in the future.

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