Title: Computational Photography based on 8-D Reflectance Field

Author(s): Tagawa, Seiichi

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Osaka University
The appearance of an object depends on its reflectance. Here, appearances depend on the reflectance, illumination, and observation. Of the three factors that control appearance, reflectance is the most difficult to deal with. An eight-dimensional reflectance field can completely represent an appearance consisting of the reflectances of objects, illumination, observation, and interreflections between objects. However, because of the high dimensionality, 8-D reflectance fields have not been developed.

To realize practical use of an 8-D reflectance field, I have designed a measuring system, a computing framework, and a rapid measurement method for a 4-D reflectance field and applied them practically.

In designing the system, one of the important issues is how to uniformly deal with the rays in a scene. Ideally, many projectors and cameras should be placed spherically around the target scene. However, such a system is infeasible. So, I developed a polyhedral mirror named the turtleback reflector, exploiting characteristics of an ellipsoid and geodesic domes that are approximately regular polyhedrons. Combining the turtleback reflector with a projector and camera, many virtual projectors and cameras can be placed uniformly but sparsely on a hemisphere. Doing this makes it possible to measure entire 8-D reflectance fields.

Next, I solved the problem of there being no computing framework for 8-D reflectance fields. I have proposed a framework for imaging with 8-D reflectance fields that unifies various individual computational photography techniques. Here, I show the formulations of three computational photography techniques in my framework and the computational result using my system with the turtleback reflector.

Another problem is the measuring time of reflectance fields. Measuring time is very long even for a 4-D reflectance field because although the light reflected in various directions can be captured at the same time, we cannot simply illuminate the scene in various directions to acquire reflected light for each illumination. Accordingly, I have developed a method for rapidly measuring reflectance properties in 4-D reflectance fields. This method exploits the dichromatic reflection to analyze the angular period of each
illumination direction, which makes it possible to separate the reflected light for each illumination. This adaptive method acquires reflectance properties rapidly.

Finally, I show the usefulness of 8-D reflectance fields. Although few techniques have been proposed that use 8-D reflectance fields, this does not mean the applications are useless. I propose a useful application, the hemispherical confocal imaging. This technique can capture only a particular depth clearly, only when the measuring system provides 4-D illumination and observation in various directions on a hemisphere around the target.

In this research I have established the fundamental techniques for practical 8-D reflectance field imaging by designing a measuring system, rapid measurement technique, method of computation, and novel computational photography techniques.