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Article / Book Information

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Title(English)	Development of single capture photometric stereo methods
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種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

専攻： Department of	物理情報システム　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Photometric stereo is an optical 3D measurement technique and has been an important research topic in computer vision. Its capability of retrieving fine surface structures of high-spatial frequency and simple experimental setups are preferable to applications in a wide class of scenes such as digital archives and medical imaging. On the other hand, it has remained a hard task to apply photometric stereo to dynamic scenes, the methods generally require multiple input images. Although some studies have extended the conventional photometric stereo method toward dynamic scenes by introducing spectral- or/and time-multiplexing or multi-view augmentation techniques, these techniques require multiple frames or cameras, and prior knowledge of surface color is required for surface reconstruction from a single capture with enough accuracy. The single-capture approach has a benefit that it demands less assumptions on surface motion and a compact setup. Despite its importance, the single capture photometric stereo methods still have remained an open problem.

In this dissertation, we developed single capture photometric stereo methods against colored Lambertian surfaces. To the best of our knowledge, our methods are the first attempts with sufficient accuracy under the corresponding assumptions to reconstruct the surface color and surface normal field from the single captured image of a colored surface.

In chapter 1, we introduce the 3D reconstruction issue in computer vision and lead to our central topic. Especially the radiometry-origin advantage of photometric stereo is briefly discussed in comparison with geometry-based 3D measurement methods. The outline of the dissertation is given in this chapter.

In chapter 2, we summarize the radiometry-based light transport and the photometric stereo linear problem. We next give a general expression of color photometric stereo, based on which our methods are discussed as appropriate forms. Related works are introduced and compared against our methods especially with a discussion on the difficulty of colored surface reconstruction from a single capture.

In chapter 3, we introduce a hyperspectral camera and propose a spectrally and spatially designed illumination to simultaneously obtain the reflectance spectra and surface normal field of an arbitrary colored Lambertian surface. Broad bands of reflectance spectra and multiple shadings are embedded in a hyperspectral image due to our illumination setup, assuming the reflectance values are not zero at bands for shading acquisition. The lost spectral information is interpolated assuming the smoothness of reflectance spectra. Hyperspectral imaging techniques have been developed recently and are now becoming a practical option. Its advantage of acquiring full-spectral information is even necessary in some medical analyses, and thus useful applications are expected. We evaluated the accuracy of our method in simulations and showed the practical effectiveness against real scenes. Some of reflectance spectra in real world materials have almost zero reflectance values over some wavelength region, and shading images are not observed in such cases. We also discuss this issue and suggest an illumination spectrum with multiple candidate bands used for shadings in simulations.

In chapter 4, we present a single capture photometric stereo method for multi-colored surfaces by using a single RGB digital camera. Although our first method presented in chapter 3 includes arbitrary colors as its targets, the low capture speed, low SNR, and high cost performance of hyperspectral cameras is still problematic. To resolve this problem and enables a more practical setup, we develop a surface color classification and determination theory under multi-colored surface under multi-colored illumination and the practical algorithm. We discuss the target class of surface color distribution on a multi-colored surface, where surface regions of the same color are determined uniquely and the surface normal is estimated. It is shown that some classification ambiguities remain in principle, and a resolution is also presented. Using an intuitive expression, the method requires that the target surface is covered with a countable number of reflectance spectra and has a sufficiently curved geometry. These assumptions as well as the single input is much less demanding than or comparable to existing methods, and yet achieved

a satisfactory surface reconstruction. We evaluated the accuracy of our method in simulations for synthetic multi-colored surfaces and conducted experiments against real materials painted with multi-colors. In the rest of this chapter, we suggest a further possibility of the method by assuming multi-band camera. The classification ambiguities mentioned above are shown to be relieved by unambiguous color classification in this setup. We discuss this issue and show simulation examples.
In chapter 5, we discuss a generalized single-capture method using a multiband camera. Based on the two methods based on global spectral and geometric information, we consider a sufficient number of bands and suggest illumination designs that enable surface reconstruction.

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