論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	A Practical One-Shot Multispectral Imaging System Using a Single Image Sensor
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出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第9624号, 授与年月日:2014年9月25日, 学位の種別:課程博士, 審査員:田中 正行,奥富 正敏,蜂屋 弘之,大山 真司,小酒 英範
Citation(English)	Degree:, Conferring organization: Tokyo Institute of Technology, Report number:甲第9624号, Conferred date:2014/9/25, Degree Type:Course doctor, Examiner:
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

A Practical One-Shot Multispectral Imaging System Using a Single Image Sensor

by

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Dissertation

Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Engineering
in the Department of Mechanical and Control Engineering
Graduate School of Science and Engineering
Tokyo Institute of Technology
August 2014

Dissertation Outline

The energy of light emitted from a light source and reflected by an object continuously spans a wide range of wavelengths. A conventional color imaging system observes only three spectral bands, typically called RGB bands, among the continuous wavelengths. This is because the conventional color imaging system imitates the human visual system. However, a considerable amount of potentially available spectral information is lost. In contrast, a multispectral imaging system with more than three spectral bands can offer reliable spectral information that is very useful for many computer vision and image processing applications including digital archive, high-fidelity color reproduction, relighting, segmentation, and tracking. However, existing multispectral imaging systems still have limitations in terms of size, cost, and real-time processing.

In contrast to existing multispectral imaging systems, single-sensor imaging with a color filter array (CFA) and demosaicking is well-established for current compact and low-cost color digital cameras. The extension from the CFA to a multispectral filter array (MSFA) enables us to capture a multispectral image in one shot without increase in size and cost. However, the extension from the CFA to the MSFA is not straightforward and there are several challenges to do this including the design of the MSFA, the development of the multispectral demosaicking algorithm, and the design of spectral sensitivity functions (SSFs) of the sensor.

In this dissertation, we address the above challenges and propose a practical one-shot multispectral imaging system using a single image sensor with a MSFA. The outline of the dissertation is as follows.

Chapter 1 Introduction. In this chapter, we explain motivations of this research with a brief review of existing multispectral imaging systems and their problems.

Chapter 2, A One-Shot Multispectral Camera Prototype. In this chapter, we develop a practical one-shot multispectral camera prototype. We first propose a novel high-performance demosaicking algorithm and a novel five-band MSFA pattern suitable for the proposed demosaicking algorithm at the same time. This joint design of the demosaicking algorithm and the MSFA pattern significantly improves the quality of acquired multispectral images. Then, based on the proposed demosaicking algorithm and five-band MSFA pattern, we develop a real one-shot multispectral camera prototype, which can capture a five-band full-HD multispectral video at 30fps. To the best of our knowledge, it is first attempt to develop a high-quality one-shot multispectral camera prototype in a compact digital camera fashion.

Chapter 3, Toward a More Accurate System. In this chapter, we discuss some improvements of the developed multispectral camera prototype toward a more accurate system. Specifically, we discuss the following three aspects.

- Further improvements of the demosaicking algorithm. Although our proposed demosaicking algorithm in the chapter 1 can give a reasonably high performance, there is still room for improvements. Here, we improve the algorithm by proposing a novel residual interpolation (RI) and incorporating the RI into the demosaicking algorithm.

- Study on an optimal number of spectral bands. Here, we discuss an optimal number of spectral bands for our proposed one-shot multispectral imaging system. We first generalize our proposed MSFA and demosaicking algorithm to evaluate a different number of spectral bands. Then, we experimentally investigate the optimal number of spectral bands in the scope of our proposed MSFA and demosaicking algorithm.

- Optimization of SSFs. Here, we discuss optimize SSFs for the proposed MSFA and demosaicking algorithm. We first propose a simple optimization framework to find optimal SSFs considering our proposed MSFA and demosaicking algorithm. Then, we find the optimal SSFs in terms of the estimation accuracy of the spectral reflectance.

Chapter 4, Direct Spectral Reflectance Estimation. In this chapter, we propose a novel spectral reflectance estimation method. The acquired multispectral image by our proposed system can be used directly or transformed to some different domains, representatively, the spectral reflectance, the sRGB, or the Adobe RGB domain. Although this depends on applications, one of the most important tasks in multispectral imaging is the accurate estimation of the spectral reflectance. In contrast to a typical approach, which estimates the spectral reflectance after demosaicking, our proposed method accurately estimates the spectral reflectance directly from raw MSFA data acquired by our proposed one-shot multispectral imaging system.

For each chapter, we conduct experiments to demonstrate the advantages of our proposed system over existing one-shot multispectral imaging systems and a conventional color imaging system.

Chapter 5, Conclusion and Future Works. In this chapter, we conclude the dissertation and briefly discuss future works.