Computer Vision and Image Understanding 113 (2009) 1170–1179

Contents lists available at ScienceDirect

Computer Vision and Image Understanding

journal homepage: www.elsevier.com/locate/cviu

Correction of color information of a 3D model using a range intensity image

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ARTICLE INFO

Article history:
Received 1 May 2008
Accepted 27 March 2009
Available online 9 April 2009

Keywords:
Range intensity image
Color image
Registration
Texture mapping
3D model
Color correction

ABSTRACT

Most active optical range sensors record, simultaneously with the range image, the amount of light reflected at each measured surface location: this information forms what is called a range intensity image, also known as a reflectance image. This paper proposes a method that uses this type of image for the correction of the color information of a textured 3D model. This color information is usually obtained from color images acquired using a digital camera. The lighting condition for the color images are usually not controlled, thus this color information may not be accurate. On the other hand, the illumination condition for the range intensity image is known since it is obtained from a controlled lighting and observation configuration, as required for the purpose of active optical range measurement. The paper describes a method for combining the two sources of information, towards the goal of compensating for a reference range intensity image is first obtained by considering factors such as sensor properties, or distance and relative surface orientation of the measured surface. The color image of the corresponding surface portion is then corrected using this reference range intensity image. A B-spline interpolation technique is applied to reduce the noise of range intensity images. Finally, a method for the estimation of the illumination color is applied to compensate for the light source color. Experiments show the effectiveness of the correction method using range intensity images.

1. Introduction

Constructing textured three-dimensional (3D) models of real objects is an important issue in the field of computer vision. The texture mapping technique [1] using color images captured by a digital camera is often used for creating a realistic 3D model. However, the illumination under which color images are captured cannot usually be controlled, and thus the color information is affected by the illumination. There are several approaches to address this problem. Some methods actually control lighting conditions for the purpose of measuring reflectance properties, e.g. [2–4]. Ikeuchi and Sato [2] measure reflectance properties with a range image and a brightness image. Kay and Caelli [3] reconstruct reflectance properties from one range image and four or more color images under different point light sources. Sato et al. [4] acquire multiple range and color images by rotating an object and construct a whole 3D model with complex texture. In these methods, a Torrance–Sparrow model [5] is modified and used to separate diffuse and specular components and recover reflectance properties. Bernardini and Rushmeier [6] present a broad survey of techniques for 3D model acquisition including reflectance properties. Tominaga and Tanaka [7] and Tan et al. [8] separate the diffuse and specular components from a color image.

An active range sensor measures distance by projecting light (laser or incoherent) onto a surface and measuring a property of the reflected light (triangulation angle, time-of-flight, etc.). The amount of reflected light is a function of the reflectance properties of the measured surface point. The array of the measured power produces an intensity image with the same sampling pattern as the geometric component of the range image. This is called a *range intensity image* or a *reflectance image*. Hereafter, this paper uses the term *range intensity image*. The use of range intensity images for registration of a range image and a color image has been successfully demonstrated before [9–13].

In this paper, we focus on another useful feature of a range intensity image [14,15]. The lighting condition yielding the range intensity image is controlled since this image is taken under known lighting conditions by virtue of the geometric sensing process. This paper investigates the application of a range intensity image to the correction of the color information of a colored 3D model. The goal is to exploit the respective advantages of a range intensity image and a color image. The controlled sensing geometry on both the illumination and observation sides, combined with the measured surface geometry, allows the inversion of an illumination model and the derivation of a corrected range intensity image representing the intrinsic reflectance properties of the surface. Using the corrected value of the range intensity image, we can adjust the intensity level of the color image. By conforming the value of the color image to that of the range intensity image, the proper

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doi:10.1016/j.cviu.2009.03.015

intensity level is obtained without estimating the illumination for the color image. Additionally, we introduce the method to estimate the illumination color proposed by Lehmann and Palm [16], and compensate for the chromatic properties of the illuminant.

This paper is organized as follows. In Section 2, we explain the characteristics of a range intensity image and show the flow of the correction method. In Section 3, we describe the method for correcting the intensity of a color image using a range intensity image. After introducing the method to estimate the illumination color in Section 4, we show several experimental results in Section 5, and then we conclude the paper in Section 6.

2. Outline of the correction method

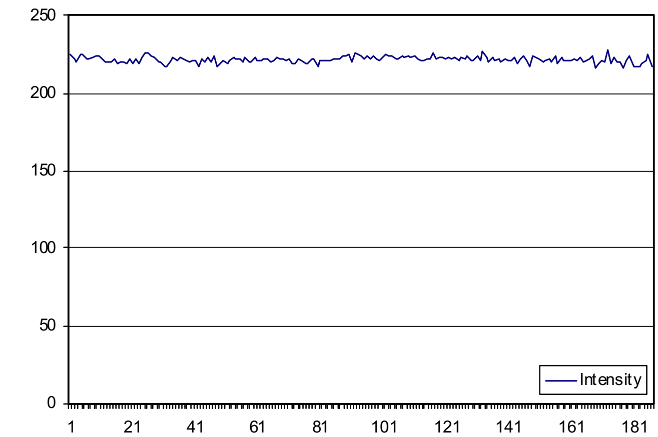
2.1. Characteristics of a range intensity image

Fig. 1 shows an example of a range intensity image and a color image of the same object. A range intensity image is monochrome (with some exceptions such as [17]) while a color image contains multiple channels, usually red, green and blue. Thanks to sustained advances in the resolution of off-the-shelf digital cameras, a typical color image is denser than a range intensity image. Additionally, a color image usually exhibits a better S/N (signal-to-noise) ratio. Fig. 2 shows cross-sections of a the red channel of a color image and of a range intensity image for a white and flat surface. They were acquired using the experimental system described later. The difference of S/N ratios is obvious. One cause is the effect of laser speckle [18]. Nevertheless, a range intensity image can be useful because, as indicated above, its illumination geometry and power can be controlled at capture time, and thus it can serve in the estimation of surface reflectance properties. Table 1 summarizes the comparison of characteristics between a color and a range intensity image.

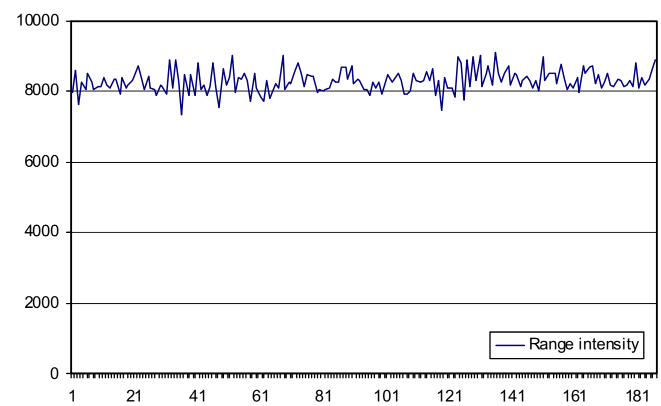
2.2. Flow of the correction method

Fig. 3 illustrates the flow of the correction method. In the first step, a reference range intensity image without shading and highlights is obtained. Secondly, the reference range intensity image is projected onto the color image plane. The ratio between the range intensity value and the color value at each corresponding point is computed. Then, correction of intensities of the entire color image is achieved by multiplying the RGB values by the ratio values interpolated at each point of the color image. Finally, the illumination color is compensated by applying the method of [16].

We assume that a range intensity image is not affected by ambient light, and that light sources for a color image are composed of a uniform color.



(a)Color image

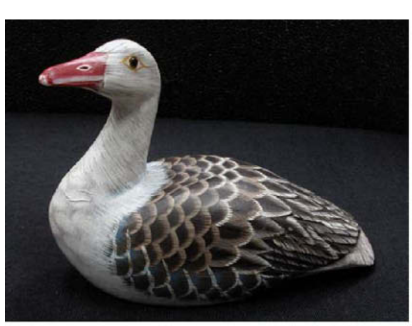


(b)Range intensity image

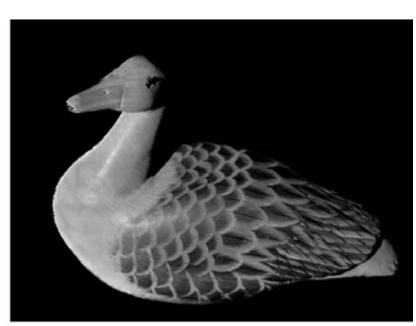
Fig. 2. Comparison of S/N ratio between color and range intensity images. Range intensity image has lower S/N ratio.

Table 1
Comparison of color and range intensity images.

	Color image	Range intensity image
Color	RGB	Intensity only
Resolution	High	Low to medium
S/N ratio	High	Low
Illumination	Unknown	Controlled



(a)Color image



(b)Range intensity image

Fig. 1. Comparison of color and range intensity images. The main differences between the two are summarized in Table 1.