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Improvement of Color Information in the Generation of 3D Models of Real Objects Using Range Intensity Images

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Abstract. Texture mapping on scanned objects, which is the method to map color images on a 3D geometric model measured by a range image sensor, is often used for constructing a realistic 3D model. Color images are affected by the illumination conditions. Therefore, discontinuities of seams occur when simply applying texture mapping. In this paper, we propose a method for correcting the discontinuities using a range intensity image. A range intensity image is a kind of intensity image that is related to the reflectance ratio of the measured points, simultaneously acquired with a range image using an active range sensor. The method estimates the color information that is not affected by the lighting environment using multiple color images and a range intensity image. As a result, the method is effective to construct a 3D model with seamless color images. The effectiveness of the correction method is illustrated by experiments with real-world objects.

Introduction

In recent years, research to construct 3D models of real objects by measuring the geometry and color information of the objects has increased in importance [1]. Texture mapping [2] on scanned real world objects, which is the method to map texture images measured using a color sensor on a 3D geometric model measured by a range sensor, is one of the methods for constructing realistic models. This technique presents some geometrical and optical issues. The geometrical issue related to the geometrical structure of the 3D model is the registration of the range and color images captured by different sensors. Traditionally, the registration had been performed manually by associating feature points between two images. Recently, an automated method has been proposed, which makes it possible to automatically generate a 3D model [3].

On the other hand, the optical issue related to the appearance of the model is the removal of the influence of the illumination environment that occurs in color images captured by a color camera. Highlights and shadows occur in the color image according to the position of the light sources and viewpoint. If texture mapping is simply applied, false color seams occur on the surface of the object due to the optical issue. Moreover, it is necessary to consider the illumination color.

Therefore, it is necessary to remove the effects of the illumination environment in color images, and various methods that solve the problem have been proposed. Sato et al. [4] have proposed a method for estimating parameters, such as the illumination environment and the object surface reflectance properties when shooting, based on the target object surface brightness in the image. However, this method requires a large number of input images taken with the object placed on a rotating platform. On the other hand, methods that estimate the position of the light color and surface reflectance properties from a single color image have been proposed. However, this approach has limitations in an illuminated environment [5].

A method to correct the intensities of a color image is proposed using a range intensity image [6]. A range intensity image, which is also called a reflectance image, refers to the intensity image that is acquired simultaneously with the range image captured using an active range sensor. A range intensity

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image has an important property in which illumination conditions, such as the geometrical arrangement and power of illumination, can be controlled at the capture time. This allows for the estimation of the reflectance properties of an object. By using the reflection property estimated from the range intensity image, the intensity level of the color image can be corrected. Furthermore, Kusanagi et al. [7] improved this method and constructed a 3D model of a real-world object. However, these methods have problems, such as seams becoming discontinued and colors close to blue and green becoming unnatural after correction. The latter problem is caused by the fact that the laser color of the range sensor is red.

In this paper, we propose a method that is effective to construct 3D models without the effects of an illumination environment, such as specular reflection, shading, and discontinuities of seams. It is generally known that saturation and lightness vary due to the effects of shading, but hue rarely does. Therefore, the true value of the hue is estimated from multiple textures using a voting strategy. However, the manner in which saturation and lightness vary has not been clarified. This method assumes that saturation and lightness decrease linearly as luminance decreases, and the the true value of saturation and lightness is estimated using multiple textures and range intensity images.

Overview of generating a 3D model

We construct a 3D model using the method of Kusanagi et al. [7]. Fig.1 shows the flow. First, multiple range images and range intensity images are obtained using a range image sensor. Range intensity images are corrected because they are affected by optical issues and sensor-specific characteristics. Secondly, the omnidirectional geometric model with intensity information is constructed by registering and integrating multiple range images and range intensity images simultaneously. The intensity information that the omnidirectional geometric model inherits is used for the correction of color images. Next, multiple color images are acquired and corrected. The correction of color images is conducted in two steps. The first step is to compensate for the illumination color by taking advantage of the method used to estimate an illumination color [8]. The second step is to estimate the true value of color using range intensity images. Finally, a 3D model with color information is constructed by texture-mapping the corrected color images.

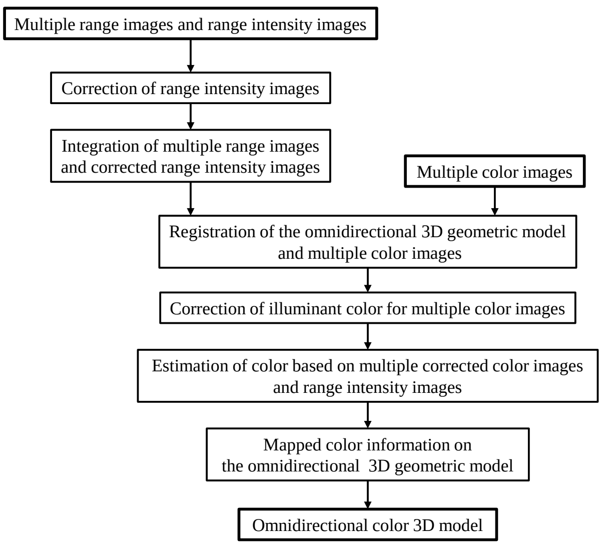

Fig. 1: Flow of constructing a 3D model with corrected color [7]

Correction of color image

Compensation of illumination color We use the Lehmann and Palm's method [8] to compensate for the illumination color. This method estimates the illumination color using changes of chromaticity in regions containing specular reflection. With the chromaticity of illumination color (p_r, p_g) estimated by this method, we compensate for the illumination color by modifying the intensity values of the color image (R, G, B) with the following equation.

$$\begin{pmatrix} R_{new} \\ G_{new} \\ B_{new} \end{pmatrix} = \begin{pmatrix} \frac{p_g}{p_r} R \\ G \\ \frac{p_g}{1-p_r-p_g} B \end{pmatrix} \tag{1}$$

Estimation of color When the intensity information (i.e., a reference range intensity image) of an omnidirectional geometric model is obtained, it can be used as the reference for correcting a color image. First, the registration of the omnidirectional geometric model and color image is necessary before the correction. We apply the registration method given in [9], which provides the intrinsic and extrinsic parameters between the geometric model and the color image with a method based on SIFT[10]. Secondly, we estimate the color from which the effects of shading are removed using multiple color images and range intensity images. The omnidirectional geometric model is projected onto the color image. The projected points of the omnidirectional geometric model are generally sparser and not aligned with the color image pixels. Thus, we obtain the color values of multiple color images at the projected point with bilinear interpolation. We convert the color images from RGB space to HSL space.

As reported above, a different approach is used to estimate the hue and saturation/lightness. True values of hue are estimated by voting because hue is less susceptible to shading. First, hue is divided into 20 domains, and the values obtained from multiple color images are sorted. Next, we obtain the domain of highest number of votes and use the averages of the values contained in the domain as estimates. The textures with specular reflection can then be removed because their hue is largely different from that of texture that does not contain specular reflection.

Saturation and lightness are affected by the shading; thus, it is necessary to remove its effect. This method assumes saturation and lightness decrease linearly as the luminance decreases by the shading. Therefore, we estimate the true value of the saturation and lightness using the intensity information of an omnidirectional geometric model that is less susceptible to the lighting environment as an alternative to the true value of luminance values. The R channel is used as an alternative to the luminance because it is the most similar to the color of the range image sensor's laser. However, the intensity information and the R channel are not the same; thus, we correct the range intensity image by matching the average and standard deviation to the R channel as follows.

$$y = \frac{\sigma_{red}}{\sigma_{intensity}} x + (\overline{x_{red}} - \frac{\sigma_{red}}{\sigma_{intensity}} \overline{x_{intensity}}), \tag{2}$$

where x and y are the intensity information before and after correction respectively, σ_{red} and $\sigma_{intensity}$ are the standard deviations of the R channel and intensity information respectively, $\overline{x_{red}}$ and $\overline{x_{intensity}}$ are the averages of the R channel and intensity information, respectively. We then approximate linearly the relationship between the R channel and saturation/lightness by using Tukey's biweight given in Eq. (3).

$$\begin{gathered} \sum_{i=1}^{n} w_i(d) d^2 \rightarrow min \\ d = y_i - (a x_i + b) \\ w_i(d) = \begin{cases} \left[1 - (\frac{d}{W})^2\right]^2 & |d| \leq W \\ 0 & |d| > W \end{cases} \end{gathered} \tag{3}$$

where y_i is the saturation or lightness, x_i is the R channel, $w_i(d)$ is the weight, and W is the acceptable range of error. The estimated value is calculated from the intensity information using

$$y_i = ax_i + b. \tag{4}$$

The color values vary in the entire model because these processes are performed for each projection point of the omnidirectional geometric model. Therefore, if the hue of the adjacent projection point is close, we determine that they are almost the same color and average the saturation and lightness.

Experiments

Experimental setup. The range image sensor used for the experiments is the ShapeGrabber system with a scan head SG-102 on a PLM300 linear displacement mechanism. The system projects a slit laser light and measures distances to the projected slit by triangulation. The number of measured points for each slit is 1280. Some sensor-specific characteristics were obtained by preliminary experiments. Applying the sensor-specific characteristics, the obtained range intensity I_{obs} can be described as follows [7].

$$\begin{aligned} I_{obs} &= \left[k_i(l_c) \frac{\cos\theta_c}{l_p l_c} I \right]^{0.45} \\ k_i(l_c) &= a_i l_c^2 + b_i l_c + c_i \end{aligned} \tag{5}$$

where I is the compensated value, θ_c is the angle between the normal and the direction to the camera, l_p and l_c are the distances to a measured point from the projection center of the laser projector and from the lens center of the CCD camera, respectively, 0.45 is the gamma value, and $k_i(l_c)$ is a 2nd-order polynomial function that corrects the nonuniformity of the laser slit and the vignetting effect of the lens in the CCD camera. For the capture of color images, a Nikon D70 digital camera was used. The acquisition format was set to RAW. The size of the color images is 3008 × 2000.

Construction of a 3D model with color texture. Fig.2 is the model used in this experiment. Fig.3(a) shows the geometric model with intensity information, Fig.3(b)-(d) show the results obtained when constructing a 3D model with color texture. Five color images are used for Fig.3(b),(c), and twelve color images are used for Fig.3(d). The effectiveness of the proposed method is obvious when comparing Fig.3(a) (without correction of the color image) and Fig.3(c) (with correction of the color image by the proposed method). We can see the discontinuities of seams and shade due to the influence of the illumination environment for Fig.3(a). In contrast, we can see that the discontinuities of seams and shade are eliminated in Fig.3(c). In addition, the proposed method can produce a more natural color than that in Kusanagi et al. [7].

Fig. 2: Model

Fig. 3: Experimental result

Summary

We have proposed a method for constructing a 3D model seamless color texture. To remove the influence of the illumination environment, the correction of the color image was conducted in two steps. The first is to compensate for the illumination color using the method in [1]. The second is to remove the highlights and shadows using a range intensity image. The experiments showed the effectiveness of the proposed 3D model construction method using range intensity images.

We assume that saturation and lightness decrease linearly as the luminance decreases in this paper. In future work, we aim to improve it. In addition, we intend to construct a method to retrieve a specular component and represent the material more accurately.

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Emerging Technology in Precision Engineering XIV

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