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Shape and Color Comprehensive Reconstruction Technology

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Abstract

The key problem of computer vision reconstruction technology is to improve accuracy of shape reconstruction and authenticity of color reconstruction. First, color edge Gray code is presented, which encodes with red and blue Gray code stripes, and decodes with sub-pixel located stripe edges. So quantization error and decoding error were eliminated and accuracy of shape reconstruction was improved. Second, color correction method is presented. The coupling phenomena of RGB primary colours existed in the encode and decode process was analyzed, and then Color coupler Correction scheme based on Caspi model Hardware Calibration was designed. Accordingly, a color imbalance caused by the surface curvature in the reconstruction process was analyzed, and color imbalance correction scheme used surface geometric information was also proposed. Shape reconstruction experimental results show that relative error of reconstructed plane is 0.05%, and reconstructed complex surface has same visual effects as real surface. Color reconstruction experimental results show that color of reconstructed surface is uniform after correction, which has same color as real surface. And moreover, This method has strong anti-interference ability and can help to improve the accuracy of shape and color reconstruction.

***Keywords**: Structured light, Shape reconstruction, Color reconstruction, Gray code*

1. Introduction

In reverse engineering, rapid prototype and other fields, it is urgent needed to obtain shape information and color information to complete shape reconstruction and color reconstruction of objects. Structured light method of vision reconstruction technology has the advantages of non-contact, high-performance and speed, highly automated, low-cost *etc.*, [1-3], and is widely used in medicine, archeology and automobile industries. The time encoding method of structured light method has high accuracy in shape reconstruction, also reconstruction efficiency is taken into account. In particular, the grey edge Gray code [4, 5] reduces the theoretical error of traditional Gray code, and increases accuracy. While the white stripe diffusion constrained further improvement of accuracy. With the progress of image processing technology, color encoding becomes the development trend with more potential. Compared with grey information, characteristics of color information is not easy to be confused. In this paper, adopting red and blue stripe instead of the traditional black and white stripe, and the color edge Gray code is presented to further improve accuracy.

At the same time that improving the accuracy of shape reconstruction, color reconstruction is also appreciated. The widely used method is to shoot color image of object under the conditions of white light, to extract color information and complete reconstruction. The acquisition and correction of color information have been studied by many research institutes

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such as IBM Technology Center, Stanford University, Tianjin University [6, 7], but the surface geometric characteristic impact on the color information and color coupling [8, 9] is not considered. In this paper, color correction method based on surface geometric characteristics and Caspi model are presented, in order to obtain real color information.

2. Shape Reconstruction Technology

2.1. Color Edge Gray Code Principle

Gray code is the optimal solution of time encoding structured light because its hamming distance is 1. Besides, red and blue have the advantage of the largest color difference, easy recognition, and the least impact to each other, so adopting red and blue stripe instead of black and white stripe to encode. When encoding, red and blue stripe patterns are projected to object surface, as is shown in Figure 1. When decoding,

--First, sub-pixel located stripe edges in every encoding image are regard as sampling points;

--Second, according to the color (red is 0, blue is 1) of sampling points in the encoding images, Gray code value can be determined, then relationship between projector sampling points and camera sampling points can be determined. For example, Gray code value of edge P in the fourth image is determined by its color of relevant position in image 1, 2, 3, and then its edge ordinal number can be figured out by equation (1)

$$k = 2^{l-i} + ((G_0 G_1 G_2 \cdots G_{i-1})_2)_{10} \cdot 2^{l-i+1} \tag{1}$$

Where k=1, 2……2l–1 is edge ordinal number; l is total number of encoding images; i=1,2……l is ordinal number of encoding images, Gi is color in encoding image i, and G0=0.

The advantages of color edge Gray code is that: the 0.5-least-bit inherent quantization error is eliminated by stripe edge decoding, edges marked by dotted line correspond with stripe interior in previous images instead of stripe edge, and their values won't be misjudged, so the 1-least-bit inherent decoding error of Gray code is reduced.

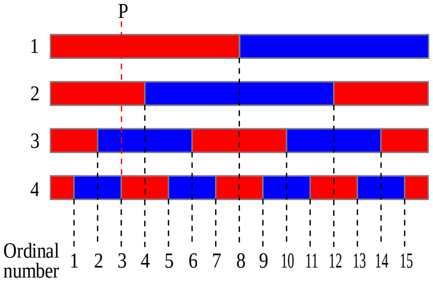
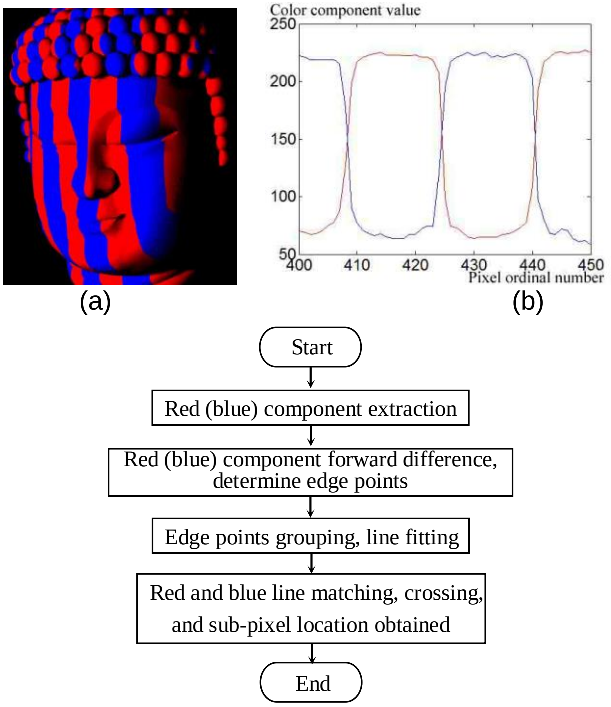


Figure 1. Color Edge Gray Code

2.2. Stripe Edge Sub-pixel Location

Accurate location of distorted edges of red and blue stripes in images, which occurs from surface geometric characteristics, is the key to ensure reconstruction accuracy. In recent years, sub-pixel location technology such as fitting method, SGDM, resampling method, space square method, and interpolation method are widely used for edge location [10, 11].

Because of large differences between red and blue stripes and the same impact to each other, intersecting point method of red and blue component curves for stripe edge location is presented. Stripes in image are similarly longitudinal direction, which is determined by encoding patterns and surface geometric characteristics jointly, so pixel color variation tendency is analyzed by horizontal scanning method. Figure 2(a) is encoding image, and red and blue component curves in the image are shown in Figure 2(b). Figure 2(c) is algorithm flow chart.



(a) (b)

(c)

Figure 2. Intersecting Point of Red and Blue Component Curves Method

3. Color Reconstruction Technology

3.1. Color Coupling Correction

Due to the color coupling caused by spectral overlap, each three primary color include the other in the encoded image, which can deduce the deformation of trapezoidal phase-shifting and can cause decoded error. This coupling degree can be affected by quality and performance of spectral filter.

Figure 3 represents the green stripe image. When only the green pattern was projected, camera image still contains red and blue components, *i.e.*, color coupling. Due to red and blue components have the same situation with color coupling, Figure 3 only represents the situation of red component. In order to correct color coupling, color calibration scheme was proposed in this paper. That is getting uncoupled standard color image by using coupled image. The calibration formula based on Caspi light model is as shown in equation 2.

$$\underset{S}{\begin{bmatrix} R \\ G \\ B \end{bmatrix}} = \underset{A}{\begin{bmatrix} a_{rr} & a_{rg} & a_{rb} \\ a_{gr} & a_{gg} & a_{gb} \\ a_{br} & a_{bg} & a_{bb} \end{bmatrix}} \underset{R}{\begin{bmatrix} r_r & 0 & 0 \\ 0 & r_g & 0 \\ 0 & 0 & r_b \end{bmatrix}} N \underset{O}{\begin{bmatrix} r \\ g \\ b \end{bmatrix}} + \underset{S_0}{\begin{bmatrix} R_0 \\ G_0 \\ B_0 \end{bmatrix}} \qquad (2)$$

Where *O* represents Projection pattern, *A* represents coupled coefficient, *R* denotes reflection parameter, *N* denotes Nonlinear transformation matrix, *S* represents Corrected image, *S0* represents image to be corrected.

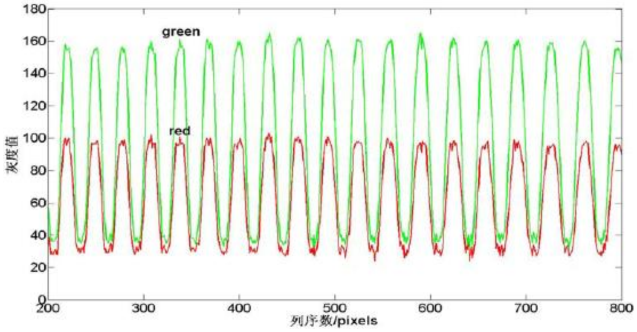


Figure 3. Color Coupling

Red, green, blue, white and black colors are all as calibration standard colors. After project them on the measured object and capture corresponding image, we can use this image information to calculate some parameters through equation 2. Then correction matrix can be constructed by these parameters to correct color coded image.

3.2. Color Imbalance Correction

Due to the inconsistent intensity range from each color, color imbalance phenomenon will occur, which can bring error when recovering the true color of the surface. The main reason of color imbalance depends on the light intensity changes caused by the geometric characteristics of the surface.

In this paper, we divide surface into many small planes, and these planes are also tangent planes nearby space reconstruction point. These tangent planes can represent local geometric properties of measured surface. So after analyzing incident and reflected light intensity, color correction factor of space reconstruction point can be calculated.

Under the premise of incidence angle is determined, the total projected area is proportional to the square of the distance of incidence. Therefore, incident light intensity is inversely proportional to the square of the distance of incidence. The incident distance of tangent plane1 and tangent plane2 is L_1 and L_2 respectively, and incident distance angle is θ_1 and θ_2. Incident light intensity ratio *A* of two facets with different geometric characteristics is as follows.

$$A = \frac{I_{i1}}{I_{i2}} = \frac{I_{iL1} \times I_{i\theta 1}}{I_{iL2} \times I_{i\theta 2}} = \frac{L_2^2 \times \sin^2 \theta_1}{L_1^2 \times \sin^2 \theta_2} \tag{3}$$

Where γ1 and γ2 denotes reflection angle of two tangent planes, *Ir1* and *Ir2* represents reflected light intensity, which meets Lambert (Lambert) equation.

Based on the incident light intensity and reflected light, color correction factor of central sampling points can be calculated by multiplying the correction factor of incident light intensity and reflected light intensity. The formula is as shown in Equation (4).

$$C = \frac{L_2^2 \times \sin^2 \theta_1 \times \sin \gamma_1}{L_1^2 \times \sin^2 \theta_2 \times \sin \gamma_2} \tag{4}$$

Choose either one of central sampling points as a reference plane, set the color correction coefficient is 1, and use equation (4) to calculate color correction coefficient Ci of central sampling points.Then multiply Ci and color information (R, G, B) to get the correction color information (Ci·R, Ci·G, Ci·B). Finally, using linear stretching method to stretch the color information into [0, 1] to get the true color information.

4. Experiments

Structured light system consists of DLP projector, color camera and computer. Camera view angle is 38°, and CCD resolution is 768×1024 pixels; Projector projecting angle is 32°, and DMD resolution is 768×1024 pixels. System range is 400mm(X)×300mm(Y), 700~1200mm(Z).

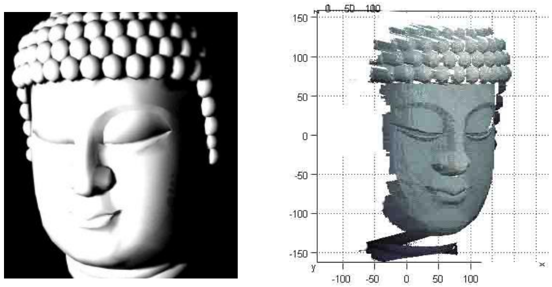
4.1. Shape Reconstruction Experiments

Standard plane perpendicular to depth direction (Z) with size 300 × 400mm^2 is reconstructed by methods and system in this paper. Standard plane moves from 700mm to 1200mm alone depth direction (Z) at intervals of 100mm, and grey edge Gray code and color edge Gray code are used to reconstruct in each position separately. As is shown in Table 1, maximum reconstruction error of grey edge Gray code is 0.60mm, maximum relative error is 0.05%; Maximum reconstruction error of color edge Gray code is 0.49mm, maximum relative error is 0.04%. Reconstruction accuracy is improved by color edge Gray code.

Table I. Reconstructed Plane Data

Depth (Z)/mm		700	800	900	1000	1100	1200
Grey edge Gray code	Absolute error/mm	0.35	0.39	0.46	0.51	0.54	0.60
	Relative error/%	0.05	0.05	0.05	0.05	0.05	0.05
Color edge Gray code	Absolute error/mm	0.30	0.32	0.35	0.41	0.45	0.49
	Relative error/%	0.04	0.04	0.04	0.04	0.04	0.04

Complex shape model is reconstructed by methods and systems in this paper. Figure 4(a) is the model, and Figure 4(b) is reconstruction results that can reflect real surface geometric characteristics.



(a) (b)

Figure 4. Reconstructed complex surface

4.2. Color Reconstruction Experiments

From Figure 5, we can see that corrected color coupling errors is 1/10 of uncorrected error, which can demonstrate the effectiveness of this method.

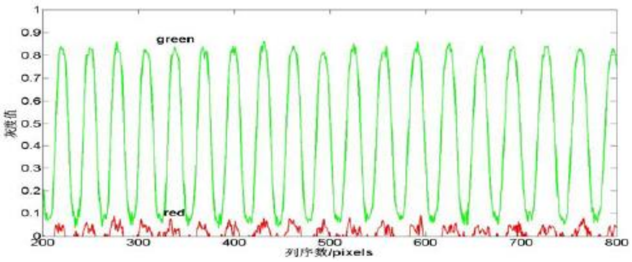


Figure 5. Color Coupling Calibration

Figure 6(a) is color image acquired by structured light system. The color of real cylindrical surface is uniform, while variation of cylinder geometry characteristic has an effect on local incident and reflected light. As a result, the color of different cylinder parts in image is different. Figure 6(b) is reconstructed surface before calibration. Figure 6(c) is reconstructed surface after calibration. Experimental results show that color of reconstructed surface is uniform after correction, which has the same color as real surface, because influence of cylinder geometry characteristic to color information is eliminated.

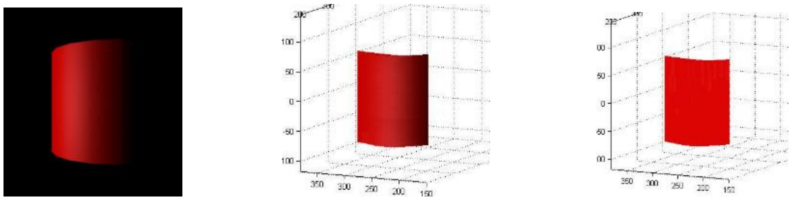

(a) (b) (c)

Figure 6. Color Reconstruction

5. Conclusion

Quantization error and decoding error are eliminated by color edge Gray code, so reconstruction accuracy is improved. Plane reconstruction error is 0.04%, and complexity surface reconstruction reflects real surface geometric characteristics. Color of reconstructed surface is uniform after correction, which has the same color as real surface, because influence of surface geometry characteristic to color information is eliminated. Feasibility and availability of methods in this paper has been verified. Further research work will focus on combining shape reconstruction, color reconstruction to obtain complete information of reconstructed surface, and do more research about color coupling and color imbalance correction.

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