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Research on Color Gray Code Encoding and Color Components Correction in 3D Measurement for Color Object

Fan Jianying, Liu Linchao, Gao Yang, Zhang Zeliang, Yu Lei and Liu Wei

The Higher Educational Key Laboratory for Measuring & Control Technology and Instrumentations of Heilongjiang Province,
Harbin University of Science and Technology,
Harbin, China
fanjianying@hrbust.edu.cn

Abstract

The existing structured light measurement technologies mainly focus on the single color objects, especially for measuring white object. Mainly because of in the process of three-dimensional measurement for color objects, color object's surface has a great influence on color components of structured light, leading to the color of structured light changing, this will cause serious errors in the decoding process. To solve this problem, combined with the actual measurements for colored objects, this paper adopts a color Gray code for encoding and decoding structured light, and presents an obtaining technical for color components of structured light, which first through regression analysis builds a mathematical model, and then uses the least squares method for solving it, at last restores the color of the projected stripes to ensure the correctness of decoding, to achieve the measurement for color object and to improve the measurement accuracy. The experimental results show that this method has a good effect on decoding.

Keywords: *Color component; Structured light; Color object, Color Gray code*

1. Introduction

Structured light three-dimensional measurement technology for color object is always one of the difficulties in structured light 3D measurement[1], recently color structured light information processing has got a great deal of attention [2].The existing color structured light image processing technology mainly around the following points: the influence of ambient light [3], the extraction of structured light stripe [4], the color component information processing [5], the information processing of the curvature of point cloud [6], and so on. Reference [7] puts forward a color classification method when using color structured light 3D measurement on human faces , which is used for the classification of the distorting color light projecting onto the human face. Reference [8] proposes a light stripe detection which has a variable illumination technology for the impact of ambient light in industrial structured light 3D measurement. Reference [9] designs a color structured light color compensation technology. Reference [10] proposes a stripe detection technology in coded structured light image.

This paper focuses on color-coded structured light three-dimensional measurement for color object, researches on encoding and decoding method of color Gray code and color components correction, in order to reduce measurement errors in decoding processing.

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2. Three-dimensional Measurement for Color Object

Three-dimensional measurement system is shown as Figure 1.

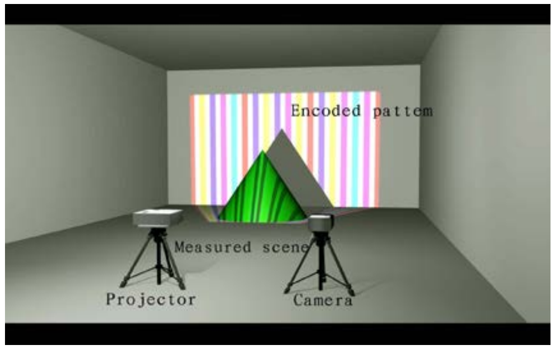


Figure 1. Three-dimensional Measurement Systems

Make three-dimensional measurement using structured light for color object, likewise need to project coded structured light on color object, use camera to take pictures, after computer processing and computing to decode the structured light, in order to achieve three-dimensional measurement, specific measuring procedure is shown as Figure 2.

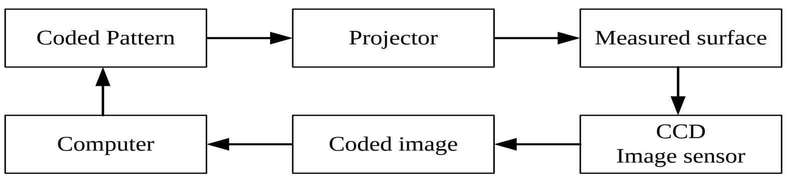


Figure 2. Measuring Procedure

After getting the pictures, due to the impact of color object on the color of shade, leading that the color of the same color structured light projected has distorted, taking on different colors, and the changes of color feature directly affect the process of light's decoding, resulting in very serious errors. That is the influence of color objects on color coding structured light. In this paper a specific measurement experiment has been carried out, as shown in Figure 3, Figure 4 and Figure 5. Specific experimental procedure is projecting the pattern of color structured light in Figure 3 onto the objects shown in Figure 4. Figure 5 is a reflected color structured light image, which is taken by camera.

Figure 3. Projected Structured light pattern

Figure 4. Color Object Model

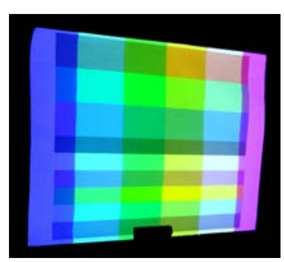


Figure 5. Colored Light is Projected onto the Color Image of the Object

By experimental observation, we can see that a single color light irradiate on objects of different colors, due to the impact of object's surface color, the color of light have changed, the change of the color characteristics of light directly affects the decoding process of light, leading to serious mistakes. This is the impact of color object on the coding of color structured light.

View of the above problems, this paper first adopts an encoding method based on color Gray code, then put forward an obtaining technical for color components of structured light according to the color of object, which is according to color components of object's surface, by image processing, combined with mathematical model to reacquire the color components of structured light, Just know that color component of each point in the image and the color components corresponding to the original object's surface, we will obtain the color of the corresponding structured light stripe at the point, in order to achieve an accurate stripe decoding.

3. Color Gray Code Encoding and Decoding Principle

Combined with the actual measurements for colored objects, we use a color Gray code for encoding the structure light, whose coding theory is similar with the gray Gray code. Select three primary colors, namely red, green, and blue stripes, the corresponding code bits respectively are 1, 2, and 3. Each color image contains red, green, and blue color component, so every color image contains three-bit Gray code, n color images contain 3n-bits Gray code, dividing the screen area into 2^{3n} aliquots. The fist projected pattern is shown as Figure 6.

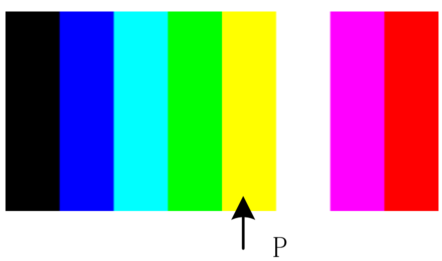


Figure 6. The First One Color Gray-code Patterns

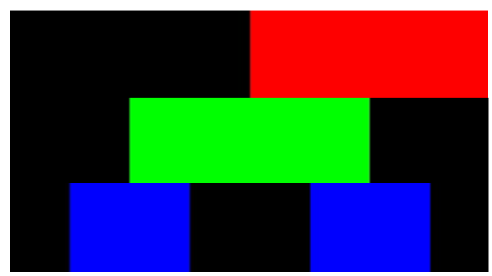


Figure 7. The First Pattern of Red, Green and Blue Components of the Distribution

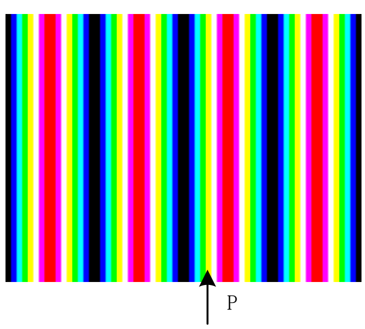


Figure 8. The Second Color Gray Pattern

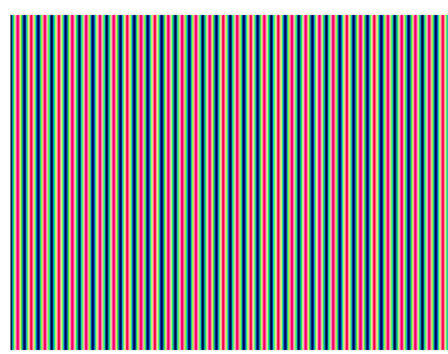


Figure 9. The Third Color Gray-Code Patterns

Among them, the first deputy of structured light contains three-bit Gray code values, dividing the spatial region into eight regions, red, green and blue respectively corresponding to the value of 1, 2, 3-bit Gray code, eight spatial regions respectively corresponding a Gray code value, For example, the point P in the figure corresponding to an area where the Gray code value is 110, shown as Figure 7.

The second deputy continues projecting Gray code structured light, meanwhile, red, green and blue three color light cycle, the style of the second color pattern is shown in Figure 8, the style of the third color pattern is shown in Figure 9.

Decoding process detects the color components of the measuring point according to the acquired color pictures, n_{th} color image corresponding from 3n-2 bit to 3n bit, red, green and blue color components respectively corresponding the three bits.

4. The Obtaining Technical for Color Components of Structured Light

This technical mainly researches on the relationship of incident light color (Stripe color), color of the reflected light (the color superimposed striped color with the target color) and surface color component, in order to restore the real color of color-coded structured light stripe that projecting onto the target surface.

4.1. The Unstauration Discussion of the Surface Color

From the theory of the reflection of light, we learn that a single color object only reflects a single color light, for example, red object can only reflect red light; white object can reflect all the light, black object absorb all the light, so presenting black. However, in the real world, there is almost no solid-colored object. As shown in Figure 10, it is the RGB tricolor fringe image taken from computer.

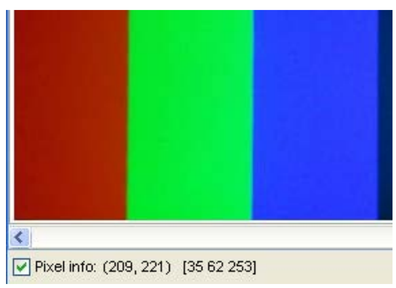


Figure 10. Red, Green and Blue Tricolor Fringe Image Taken from Computer

The pixel of coordinates $(209, 221)$ is detected in the blue region in Figure 1, if this pixel is pure blue, in their (R, G, B) value, the R and G component should be zero, actually the (R, G, B) component of that pixel is $(35, 62, 253)$,that means the R and G component isn't zero, the phenomenon of unsaturated color appears.

4.2. The Regression Analysis to Model

4.2.1. The Modeling of the Color Components Relationship:

Aim at the identical color components, set the color component of reflected light as x_1, the original color component of the object's surface as x_2, the color component of structured light as y, the polynomial regression model is:

$$y = a_0 + a_1 x_1 + a_2 x_1^{\ 2} + b_1 x_2 + b_2 x_2^{\ 2} \tag{1}$$

Among them, the coefficient a_i, b_i is obtained by estimating experimental data.

4.2.2. The Least Squares Method to Solve the Model:

Set that there are i experimental data. For each value of y, there is a fitted value y_i and an observed value $\hat{y}_i$. The idea of least squares method is to find a suitable coefficient to obtain a minimum residual sum of square D. Specific algorithm as follows:

$$D = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 = \sum_{i=1}^{n} (\hat{y}_i - a_0 - a_1 x_{1i} - a_2 x_{1i}^{\ 2} - b_1 x_{2i} - b_2 x_{2i}^{\ 2})^2 \tag{2}$$

According to the principle of calculus, we want to obtain the minimum of formula (2) required to confirm the following conditions:

$$\begin{cases} \dfrac{\partial D}{\partial a_0} = -2\sum_{i=1}^{n} (\hat{y}_i - a_0 - a_1 x_{1i} - a_2 x_{1i}^{\ 2} - b_1 x_{2i} - b_2 x_{2i}^{\ 2}) = 0 \\ \dfrac{\partial D}{\partial a_1} = -2\sum_{i=1}^{n} x_{1i} (\hat{y}_i - a_0 - a_1 x_{1i} - a_2 x_{1i}^{\ 2} - b_1 x_{2i} - b_2 x_{2i}^{\ 2}) = 0 \\ \dfrac{\partial D}{\partial a_2} = -2\sum_{i=1}^{n} x_{1i}^{\ 2} (\hat{y}_i - a_0 - a_1 x_{1i} - a_2 x_{1i}^{\ 2} - b_1 x_{2i} - b_2 x_{2i}^{\ 2}) = 0 \\ \dfrac{\partial D}{\partial b_1} = -2\sum_{i=1}^{n} x_{2i} (\hat{y}_i - a_0 - a_1 x_{1i} - a_2 x_{1i}^{\ 2} - b_1 x_{2i} - b_2 x_{2i}^{\ 2}) = 0 \\ \dfrac{\partial D}{\partial b_2} = -2\sum_{i=1}^{n} x_{2i}^{\ 2} (\hat{y}_i - a_0 - a_1 x_{1i} - a_2 x_{1i}^{\ 2} - b_1 x_{2i} - b_2 x_{2i}^{\ 2}) = 0 \end{cases} \tag{3}$$

Further finishing the group (3) to get the following equations:

$$\begin{cases} a_0 n + a_1 \sum_{i=1}^{n} x_{1i} + a_2 \sum_{i=1}^{n} x_{1i}^{\ 2} + b_1 \sum_{i-1}^{n} x_{2i} + b_2 \sum_{i=1}^{n} x_{2i}^{\ 2} = \sum_{i=1}^{n} \hat{y}_i \\ \sum_{i=1}^{n} a_0 x_{1i} + \sum_{i=1}^{n} a_1 x_{1i}^{\ 2} + \sum_{i=1}^{n} a_2 x_{1i}^{\ 3} + \sum_{i=1}^{n} b_1 x_{1i} x_{2i} + \sum_{i=1}^{n} b_2 x_{1i} x_{2i}^{\ 2} = \sum_{i=1}^{n} x_{1i} \hat{y}_i \\ \sum_{i=1}^{n} a_0 x_{1i}^{\ 2} + \sum_{i=1}^{n} a_1 x_{1i}^{\ 3} + \sum_{i=1}^{n} a_2 x_{1i}^{\ 4} + \sum_{i=1}^{n} b_1 x_{1i}^{\ 2} x_{2i} + \sum_{i=1}^{n} b_2 x_{1i}^{\ 2} x_{2i}^{\ 2} = \sum_{i=1}^{n} x_{1i}^{\ 2} \hat{y}_i \\ \sum_{i=1}^{n} a_0 x_{2i} + \sum_{i=1}^{n} a_1 x_{1i} x_{2i} + \sum_{i=1}^{n} a_2 x_{1i}^{\ 2} x_{2i} + \sum_{i=1}^{n} b_1 x_{2i}^{\ 2} + \sum_{i=1}^{n} b_2 x_{2i}^{\ 3} = \sum_{i=1}^{n} x_{2i} \hat{y}_i \\ \sum_{i=1}^{n} a_0 x_{2i}^{\ 2} + \sum_{i=1}^{n} a_1 x_{1i} x_{2i}^{\ 2} + \sum_{i=1}^{n} a_2 x_{1i}^{\ 2} x_{2i}^{\ 2} + \sum_{i=1}^{n} b_1 x_{2i}^{\ 3} + \sum_{i=1}^{n} b_2 x_{2i}^{\ 4} = \sum_{i=1}^{n} x_{2i}^{\ 2} \hat{y}_i \end{cases} \tag{4}$$

This equations have a total of five unknown numbers a_0, a_1, a_2, b_1, b_2. Through the simultaneous, work them out.

Each R, G, B components should be considered separately in the calculation of its mathematical model , each component for calculating one mathematical model.

4.3. Identification and Analysis of Model Parameters

In this paper, we make experiment through projecting nine kinds of color coded structure light stripes on the color objects. The stripe pattern is shown in Figure 11. Color flat objects are shown in Figure 12. The image of objects with color-coded structured light is shown in Figure 13.

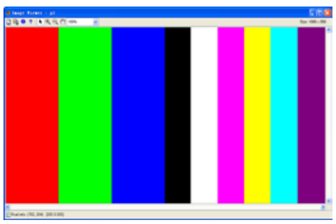


Figure 11. Color Structured Patterns

Figure 12. Light Color Object Patterns

Figure 13. The Image of Object with Structured Light

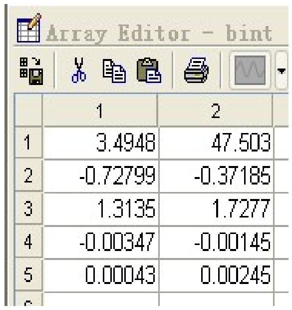
The experimental data of R, G, B components obtained are shown in Table 1:

Table 1. The Experimental Data of Color Component

Getting data of components in different stages		Group Number												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Surface color Components	R	164	170	171	170	97	96	98	97	71	69	66	64	68
	G	97	101	100	93	185	181	184	175	113	124	120	109	113
	B	130	130	130	125	163	158	159	158	247	250	254	238	242
Patterns color components	R	0	0	0	255	0	0	255	255	0	0	255	255	255
	G	255	0	0	255	0	0	255	0	255	0	255	0	255
	B	0	255	0	255	255	0	255	255	0	255	255	255	0
Image color components	R	37	29	18	230	20	7	173	190	0	79	137	141	97
	G	148	35	11	154	108	30	229	102	177	61	176	44	158
	B	18	253	45	193	255	71	228	241	91	255	255	255	99

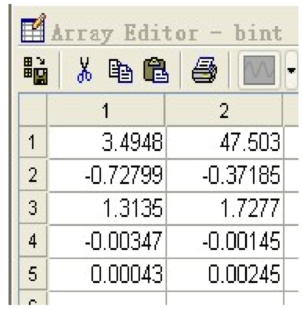
In Table 1, 1-3 rows are the color component values of object, the 4-6 rows are color component values of color structured light, 7-9 rows are color component values of the reflected light.

Adopt Matlab regression function to analysis the data, to calculate the red component value of the data, the results are shown in Figure 14 (a), Figure 14 (b) shows the confidence interval of equation coefficients. The significance level of this article is set 0.05 as the default value. It can be known from the experimental data that the stability of model is good, the volatility of coefficient is small, and we can achieve the requirements of color encoding and decoding accuracy.



	1	2
1	3.4948	47.503
2	-0.72799	-0.37185
3	1.3135	1.7277
4	-0.00347	-0.00145
5	0.00043	0.00245

(a)The model coefficients of red component



	1	2
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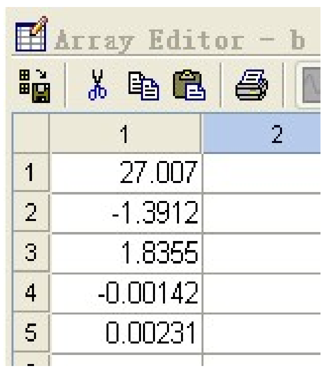
3	1.3135	1.7277
4	-0.00347	-0.00145
5	0.00043	0.00245

(b) The confidence interval of model coefficients

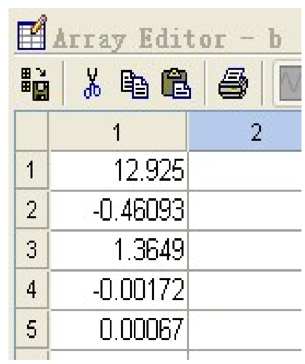
Figure 14. The Model Coefficients Value of Red Component

In the same way, respectively analysis the green and blue component, then obtain the model coefficients of the green and blue component shown in Figure 15.



	1	2
1	27.007	
2	-1.3912	
3	1.8355	
4	-0.00142	
5	0.00231	

(a)The model coefficients of green component



	1	2
1	12.925	
2	-0.46093	
3	1.3649	
4	-0.00172	
5	0.00067	

(b)The model coefficients of blue component

Figure 15. The Model Coefficients of the Green and Blue Component

Finally we can obtain regression model y_R, y_G, y_B of R, G, B component:

$$\begin{cases} y_R = 22.004 - 0.54992x_1 + 1.5206x_2 - 0.00237x_1^2 + 0.00128x_2^2 \\ y_G = 27.007 - 1.39120x_1 + 1.8355x_2 - 0.00142x_1^2 + 0.00231x_2^2 \\ y_B = 12.925 - 0.46093x_1 + 1.3949x_2 - 0.00172x_1^2 + 0.00067x_2^2 \end{cases} \quad (5)$$

5. Information Processing Experiments of Color Gray Code Structured Light

Making three-dimensional measurement for color objects, firstly, we project an all-white structured light pattern to get color components of the object which is the value of x1 in the model, and then project color Gray code pattern onto the object to get color components of reflected light which is the value of x2 in the model, at last we work out color components of structured light according to the relationship model of color components.

After that, according to its component values to determine the value to be decoded, after decoding, we can carry out three-dimensional measurement according to the measurement principle of structured light.

In this article, the projected color gray code structured light shows in Figure 16, the pattern of color object and the image of the object with structured light, which are taken by the camera show in Figure 17 and Figure 18.

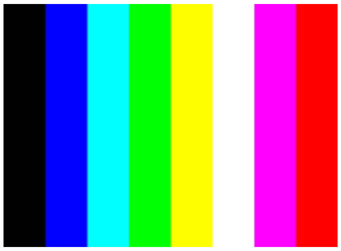


Figure 16. Color Gray Code Pattern

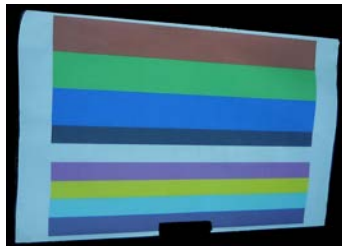


Figure 17. Color Object Patterns

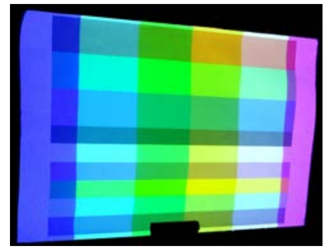


Figure 18. The Image of Object with Structured Light

The image restored by the obtaining model of color components and the decoded image are shown in Figure 19 and Figure 20.

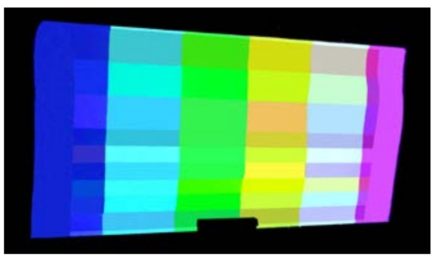


Figure 19. The Image After Restoring from Distortion

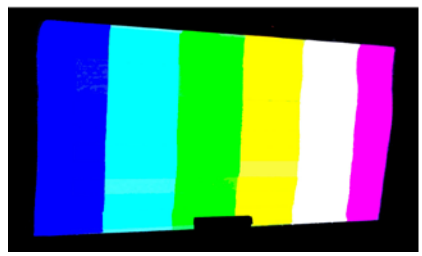


Figure 20. The Coded Structured Light Image after Decoding

6. Conclusion

It can be seen from the image of experiment that the color Gray code structured light engenders color distortions due to the color of the object's surface, through the obtaining model of color component nearly restores the original color of the structure light. Structure light patterns after decoding are the same as the original structured light pattern, achieving expected effect. The experiment result shows that a combination of both the color Gray code method and the obtaining technical for color components of structured light are useful for decoding of 3D measurement for color object, improving the measurement accuracy.

However, we can see by comparing the last two images that the color of restored structured light still have a big distance to decoding structured light's color, that's mainly caused by the error generated in building model, so further research is needed.

Acknowledgments

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