

A Color Structured Light Coding and Decoding Method Based on Regional Structured Image with Heterogeneous Applications

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Abstract

As an efficient and reliable method in 3D reconstruction and active measurement, structured light vision technology is being more and more important. Structured light vision technology by one or more image coding pattern projection to measure the scenario, and with the position of the projection direction at an angle with the camera intake scene projection image, and then match the projected image and the code pattern corresponding points using trigonometric obtain a 3D scene information. In order to achieve accurate projection image and coding pattern matching, on the one hand need effective structured light coding method, on the other hand, it is necessary to use a variety of image processing method to accurately locate the position of the projection image feature points. In this paper, a color structured light coding and decoding method based on topology structured and regional structured model is proposed. Finally, the methods for extracting encoded feature points based on waveform analysis and for classifying colors based on clustering analysis are developed. The result of the experiment has shown that the proposed method has good performance for the structured light vision system.

Keywords: *Color Structured Light, Regional Structured Image, 3D Reconstruction, Clustering Analysis*

1. Introduction

The technology of 3D shape reconstruction is a branch of computer vision technology. It is a research direction that integrates computer vision with computer image and graph processing. It has a wide application in the fields of automation process, machine vision, CAD, virtual reality, medicine and so on. It is an important but difficult problem that how we can obtain the 3D shape information of an object accurately and rapidly.

Generally, the 3D reconstruction system based on structured light is mainly divided into three sections, they are system parameter calibration, structured light coding and decoding and computing the 3D feature point information. For the structured light coding method, the use of various coding strategy allows the pixel itself with a priori encoded information, the appropriate coding strategy chosen or not affect the accuracy of the matching algorithm complexity and 3D reconstruction.

In recent years, people have done a lot of work on the method of structured light coding. The method of linear structured light based on time coding does not fast real-time reconstruction of objects, but the coding principle is simple and easy to implement [1-2].

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The existing single spatial coding method [3], although capable of real-time reconstruction of the object, but by finding corner [4] or stripe boundary [5] method to get the feature point coordinate information is not accurate enough. In most cases, the method uses of the form of color strips coding [6-8] to reconstruct, does not apply to solve unconstrained 3D information. For the structured light decoding method, Zhang *etc.* proposed a series of image preprocessing method which can be more accurately extract a finer streak of gray code [9]. Yu *etc.* use sub-pixel positioning technology based on edge direction to extract gray code stripe edges [10]. Fechteler *etc.* proposed an adaptive color classification method and 3D models capture method, which solved the influence of ambient light, color, facial features of the reconstruction quality, improved system robustness [6]. According to the potential relevance of stripe and adjacency of the picture, Brink *etc.* proposed maximum spanning tree algorithm [11]. By using this algorithm, the reconstruction results can be more accurate and more reliable than before. Kong *etc.* identify each stripe boundary by using serializable window features and spatial neighborhood coding method; they use global optimization ideas for the best neighborhood matching stripe boundary, the entire surface of the object does not need to assume monotonous, and is not strictly necessary continuity [12]. Zhang *etc.* introduce the multi-channel dynamic programming to overcome the image of the stripe occlusion problems, but there often will be set on the boundary between the regions of local monotonous decoding errors [13].

Coding and decoding technology plays an important role in data acquisition in the reconstruction of the color structured light, which affects the measurement precision, speed and reliability of the system. In the previous studies, the method of color structured light coding usually be used for spatial coding and direct coding, and can be used to measure the dynamic objects in most cases. But due to the influence the color fidelity and resolution of CCD camera we cannot get ideal effect and precision. It is not easy to find clear, unambiguous mappings. The method of 3D object measurement accuracy is not high; it is difficult to be used for the precise measurement of the object. Under normal circumstances, using more than 3 kinds of color, it's likely to have color confusion and not easy to identify the different colors, and generally the sampling density and resolution is not high. In this paper, a color structured light coding and decoding method based on topology structure and regional structured model is proposed. Through the analysis of experiment, the proposed method has better performance in some aspects.

The article is organized as follows. Section 2, 3 provides the main theory of the color structured light coding and decoding method based on topology structure and regional structured model. The results of 3D reconstruction by this method will be illustrated in the section 4. Section 5 is our concluding remarks.

2. Coding Method

Structured light coding and decoding technology is an effective method, it proactively marks the 3D object with feature points. This method can make the 3D object has more feature information of the points which can be easily identified and controlled. It mainly contains three important parts such as designing structured light coding pattern, extracting feature points and matching information of the feature points. In order to compute the 3D coordinate information of the feature points, we must accurately identify the matching relationship between each pair of feature points. Under the circumstances, the structured light coding technology has become an important means to determine the feature point's information.

All the light beams been coded is the core of the structured light detection technology. A good coding method can reduce decoding time and improve the accuracy of decoding. There are a variety of structured light coding methods such as binary code, Gray code, color coding based on random sequence, direct color coding and so on[1-3] and [6].

However, if colored stripes are closely spaced, due to the interference between the color stripes, it is difficult to accurately extract center color stripes or to calibrate color of the stripes. In this paper, we propose a color structured light coding method based on topology structure and regional structured model. This coding method has the following four advantages:

- (1) Coding for the structure of the image can satisfy the requirements of the large size, high precision.
- (2) The degree of structured coding is higher, coding image decoding accuracy is higher; the coding image of anti-interference performance is stronger.
- (3) By a single encoded image you can get the feature points of the entire space information, the capability of real-time is stronger.
- (4) The coding method is not strictly limited to the surface of reconstruction object.

In this coding method, we use eight kinds of color for image coding. But in the image coding process, it is not capable of any combination of these colors, because the color of the grey value close (such as red and magenta) adjacent combination will get in the way to decoding work and can't decode correctly, shown in Figure 1. The colors of the block are red, green, blue, black, cyan, magenta, yellow and white. The blocks of eight colors can be divided into two groups, one group is made up of red, green, blue, magenta, yellow and blue 6 kinds of color blocks, called color tuple; another group is made up of black and white two kinds of color blocks, called black and white tuple. Due to the different color tuples of gray value, we divide color tuple into two tuples. One group is composed of three color red, blue and magenta color elements, called as the high value color tuple, another group is made up of green, blue and yellow, called as the low color tuple.



Figure 1. Color Image

We use the elements from black and white tuple to form a square 3*3 region, called as white micro-area, shown in Figure 2 (a). According to the white micro-area, this time we choose the opposite color at the same position to form another region, called black micro-area, shown in Figure 2 (b). Then we choose different colors from the color tuple to form the boundary of the micro-area. If the color block of the color boundary adjacent with the element in low color tuple, then the color block should be randomly selected from high value color tuple. On the contrary, if the color block of the color boundary adjacent with the element in high color tuple, then the color block should be randomly selected from low value color tuple. If the color boundary of the upper left first color blocks is the element from high value color tuple, the color boundary should be called high value color atomic boundary, shown in Figure 3 (a). And if the color boundary of the upper left first color blocks is the element from low value color tuple, the color boundary should be called low value color atomic boundary, shown in Figure 3 (b). We use the low color atomic boundary and white micro-area to form a 5*5 square area, called low value atomic area, shown in Figure 4 (a). And we use the high color atomic boundary and black micro-area to form a 5*5 square area, called high value atomic area, shown in Figure 4 (b).

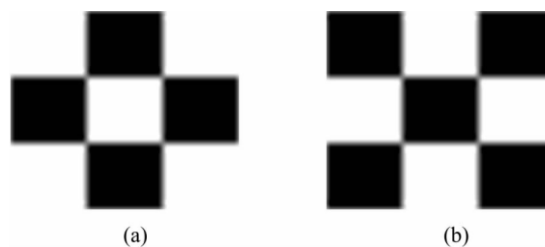


Figure 2. Regional Structured Coding Image

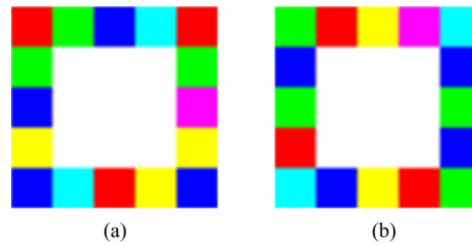


Figure 3. Color Boundary Image

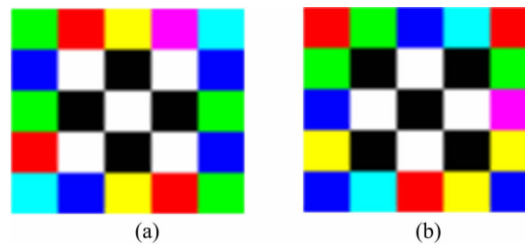


Figure 4. Regional Coding Image

The coding image is composed of high value atomic area and low value atomic area, the two different areas to should be used interchangeably. The coding image should make sure that the low value atomic area can only appear in position adjacent to the high value atomic area. The low value atomic area can be on the above of the high value atomic area or below, on the left or right side. In the same way, the coding image should make sure that the high value atomic area can only appear in position adjacent to the low value atomic area. Any color atomic boundary structure of the two high value atomic areas can have the same color sequence. In the same way, any color atomic boundary structure of the two low value atomic areas can have the same color sequence. According to the above algorithm, the coding image based on color structured light can be proposed, shown in Figure 5.



Figure 5. Coding Image

From Figure 5 we can see that, the color coding image is composed of multiple atomic areas to form the whole topology structure; each atom area code forms the local topological structure; the micro area in each atom area forms the local structured coding. So the coding image has strong anti-interference ability.

3. Decoding Method

When decoding the encoded image (decoding image) captured by the camera, first we need to get the location of the feature points in the image and the color of each feature points. Then according to the topological structure of color boundary coding and color boundary internal structure, we get the corresponding relation between each feature points in the decoded image and feature points in the original image in order to get the accurate decoding information.

3.1. Feature Point Extraction Method Based on Waveform Analysis

In the process of extraction information of the feature points, it is difficult to accurately extract the position of the coding feature points, because the color of the feature points maybe change or the structure of feature areas maybe distort. This will lead to decode the feature points inaccurately, so that we cannot correctly to reconstruct the 3D object. In order to extract the information of feature points in the coding images more accurately, the image captured by the camera should be grayed first. Then we locate the position of the feature points by using a kind of feature point extraction method based on waveform analysis.

For the grayed decoded image, each line of pixel gray value is analyzed in this method. According to the coding rules of decoding image, the gray value of each feature point will be between peaks or troughs in the decoded image grayscale waveform. When the peaks and troughs of the waveform graph are determined, we can get the accurate position of the feature points in every region and calculate the center of mass in the feature area.

In the actual waveform diagram of grey value, waveform figure is generally not a smooth curve. A shake waveform will appear in the area between the peaks and the troughs, so the area is not easy to determine. In order to eliminate the shake wave impact on the image segmentation, we need to abandon some small secondary peak in the waveform analysis, so the method of image filter is introduced. Using this method can be more effectively to get the positions of coding feature points in the decoded image.

3.2. Color Classification Based on Cluster Analysis

In the waveform analysis method is used to analyze the decoding image processing, due to the interference of pixels adjacent feature points, it is difficult to accurately determine the color of the feature points. Paper [14] proposed a color classification method based on cluster analysis, the method can effectively eliminate the interference and improve the accuracy to determine the characteristics of color. But the color classification method based on cluster analysis cannot identify the black color and need more time to identify the black color. In this paper, the method is improved. The improved method can identify any color, and reduce the processing time.

In order to determine the color of the feature points, we use $a_1, a_2 \dots a_8$ to represent the eight kinds of colors of the pixels in the structured light decoding image. The RGB values of the color a_x are expressed in $r_x, g_x, b_x, x=1, 2 \dots 8$. Assuming that the M_q represents the number of pixels belonging to the color q , and the initial values of M_q are zero. Color classification method based on clustering analysis of the implementation of the steps is as follows:

(1) Assuming $N_q=0, q=1, 2 \dots 8$. Calculate the coordinates of each coding feature point in RGB color space, respectively get the distance between the coordinates of eight kinds of color in RGB color space.

$$D(i, j, s) = \sqrt{(R(i, j) - r_i)^2 + (G(i, j) - g_i)^2 + (B(i, j) - b_i)^2} \quad (1)$$

In the equation (1), $D(i, j, s)$ represents the distance between the coordinates $(R(i,j), G(i,j), B(i,j))$ of feature point and point (r_i, g_i, b_i) .

(2) Find each coding feature points in a minimum of eight distances. If $D(i, j, q)$ is the minimum in $\{D(i, j, 1), D(i, j, 2) \dots D(i, j, 8)\}$ and q is also the minimum, that is to say the color of the feature point belongs to class q , set $N_q = N_q + 1$. According to equation (2), we write down the RGB value of the feature point.

$$I_q(N_q, a) = Z(i, j, a), a = 1, 2, 3 \quad (2)$$

If we get $N_q = M_q$ for each $q=1, 2 \dots 8$, then the color classification method based on clustering analysis come over, else go to step (3).

(3) Change the RGB values of $a_1, a_2 \dots a_k$, according to equation (3), then write down N_q for each M_q , go to step(1).

$$\begin{cases} r_q = [\sum_{i=1}^{N_q} I_x(N_i, 1)] / N_q \\ g_q = [\sum_{i=1}^{N_q} I_x(N_i, 2)] / N_q \\ b_q = [\sum_{i=1}^{N_q} I_x(N_i, 3)] / N_q \end{cases} \quad q=1, 2 \dots k \quad (3)$$

3.3. Coding Feature Point Matching

The matching method of the coding feature points is very important for calculating 3D information; each pair of feature points must be unique. After the location of the feature points is obtained by waveform analysis, we can determine the feature points of coded information according to the feature points in the positions of the decoded images. Because the feature points carry the topology information and regional structured information, so we can get the relationship between the original code and image feature points. When the feature point is decoded, we can determine the structured mode of the region through the topological relationship between the color sequence and the internal topology of color sequence because the color of each feature point sequence is unique in the code image. When the feature point is decoded, it first needs to uniquely determine the matching relationship in the region based on color coding frame 5*5 sub-region, shown in Figure 6. If the feature points are color-coded, coding feature points can be determined according to the topology of the border. If the color of the feature point is black or white, we first need to determine the location of decoding feature points by the 3*3 sub-region within the feature region, then determine the coding feature points combined with the decoding 5*5 sub-region, shown in Figure 7.

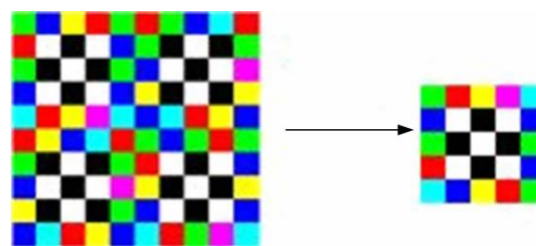


Figure 6. Decoding of 5*5 Sub-Region

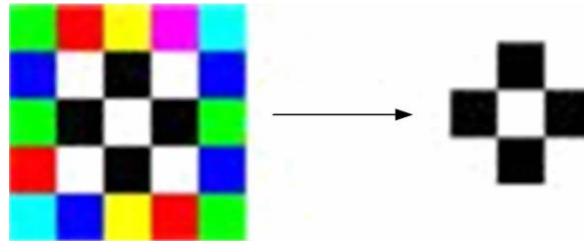


Figure 7. Decoding of 3*3 Sub-Region

4. Experiment

4.1. 3D Reconstruction System

The 3D reconstruction system based on color structured light consists of hardware part and software part. The hardware part of the system is composed of four parts, a projector, a camera, a computer and a reconstructed object. The projector is used to project the image of an encoding image to the surface of the object to be reconstructed. The camera is used to get the modulated coding structured light images. The computer is used to process the input image, and the 3D object is generated by solving the space coordinates. The hardware part of the system is shown in Figure 8. The model of the computer used in our system is DELL DIMENSION 5150. As the performance of current household projector is very well, so the common household projector can meet the requirements of this system for the projection of the projector. The model of the projector used in our system is EPSON EB W6. The camera is a key component part of the 3D reconstruction system; it is used to get the encoded image. The model of the camera used in our system is Canon EOS. The software part of the system including the camera calibration module, the projector calibration module, coding structured light image acquisition module, digital image processing module, structured light coding image decoding module, structure light feature points matching module, image and data parallel processing and calculation module and calculation module of 3D point cloud data information.

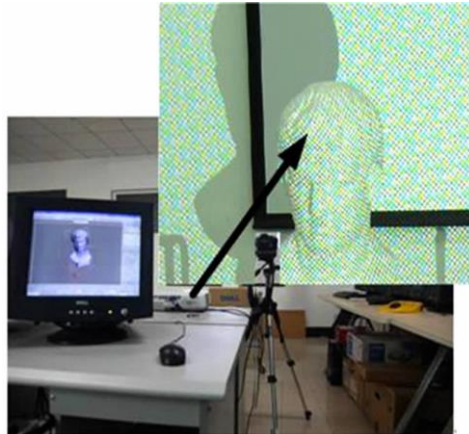


Figure 8. Experiment System

4.2. Result and Analysis

The decoding of the coding image taken by the camera is the key to the whole calculation process, the encoded image we get is shown in Figure 9.

There are 8741 feature points are decoded in the head coding image, only 13 feature points are decoded not correct, the decoding accuracy is above 99.5%. This is further evidence that the decoding method in this paper is effective. By calibration of the system

parameter and coding feature points matching, we can get the 3D head reconstruction according to the world coordinates of the feature points calculated, shown in figure 10. The process of three dimensional points cloud computing and reconstruction spent an average of less than 0.1 s. An average of up to 15 frames per second, meet the needs of the dynamic reconfiguration. After checking the size of particular feature point's reconstruction, we get a better result: the minimum error is 0.4 mm, the maximum error is 4.7 mm and the average error is 1.3 mm. From Figure 10, we can get that the 3D reconstructed model achieve the desired effect.

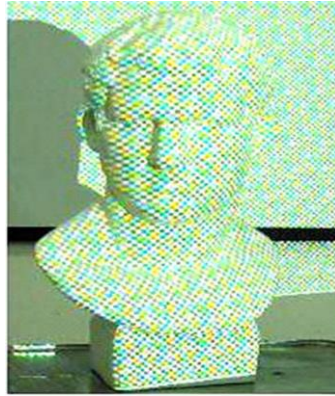


Figure 9. Modulation of Coded Image



Figure 10. Reconstruction of 3D Object

5. Conclusions

From the result of the experiment in this paper, we can draw a conclusion that the 3D reconstruction method is not only able to reconstruct the original 3D entity, and the extraction of surface characteristics of the 3D entity data is also very complete. The coding method proposed in this paper can get all the information on the surface of the 3D entity just using only one coding image. This method improved the anti-interference ability of the coding image and basically achieved the design of practicality and generality. When the encoded image is decoded, we use the waveform analysis method to refine the characteristic information and the color classification method based on clustering analysis to determine the color of the feature points. The use of these methods can effectively eliminate the interference between the colors. By using the structure of topology exists in the coding image, it can raise the accuracy of the decoding of the feature points.

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