Teaching Image Spectrum Based on Structured Light Illumination

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Abstract: In the past decade, structured lighting illumination technology has developed rapidly. It provides a convenient method for directly obtaining a single spectral component of an image. It is proposed in this paper that teaching image spectra through structured light lighting. Through image spectrum acquisition and image reconstruction, the relations between spatial and frequency domains are demonstrated vividly. Case teaching combined with group research is used to guide students to understand and process images in frequency domain.
Keywords: Structured Light Illumination; Image Spectrum; Image Analysis

1. Introduction

Spectrum is another form of information carried by the signal, which is different from the intensity distribution shown in time domain (one-dimensional signal) or space domain (two-dimensional signal). Analyzing and processing signals from a frequency domain perspective is a fundamental skill that information science and engineering students must master. Courses such as "Signal and System Analysis", "Digital Signal Processing", and "Digital Image Processing" are the most fundamental courses that involve signal frequency domain, and are also hot areas of current curriculum reform [1-5]. Fourier transform and Fourier inverse transform are the basic methods for achieving spatial frequency domain exchange of images. Because of the complexity of Integral transform and the abstraction of the concept of spectrum, image spectrum is always a difficult point in teaching. In the past decade, Structured light lighting technology has attracted attention in the field of image processing with its simple detection means, wide applicability and flexibility [6, 7]. Different from the commonly used Fourier transform, the single spectral component of the image can be extracted by the Structured light illumination based on the cosine fringe, which provides a new means for image spectrum teaching.

This paper proposes to use Structured light illumination single pixel imaging technology to explain the basic concept of image spectrum and the significance of spectrum components. Different spectrum components are used to reconstruct images, and guide students to realize that different spectrum components have different contributions to image information. On this basis, students can expand their knowledge and skills through group assignments, internalizing the frequency domain expression and processing methods of image information into basic skills.

2. Spectrum acquisition of illumination image based on Structured light

Cosine fringe is the most common form of Structured light lighting. Cosine fringes are a pattern of light intensity varying with spatial coordinates, as shown in Figure 1. The number of horizontal stripes reflects the horizontal change rate kx of the image, similarly, the number of vertical stripes reflects the vertical spatial frequency ky. In Figure 1, when the spatial frequency kx=3 and ky=0, the fringes change three times horizontally and remain unchanged vertically. Due to the conjugate symmetry of the image spectrum, there are two bright spots on the horizontal axis of the image amplitude spectrum, located at coordinates (3,0) and (− 3,0). When the spatial frequency kx=0 and ky=4, the fringes change three times along the longitudinal direction and remain unchanged horizontally. The corresponding spectrum has two bright spots on the longitudinal axis, coordinates (0, 3) and (0, − 3). If the fringes undergo periodic changes both horizontally and vertically, with kx=3 and ky=4, then the two components of the spectrum are no longer located on the coordinate axis and symmetrical about the origin. It can be seen that the spatial frequency of cosine fringe Structured light is single, and Structured light with different frequencies are orthogonal to each other in the frequency domain.

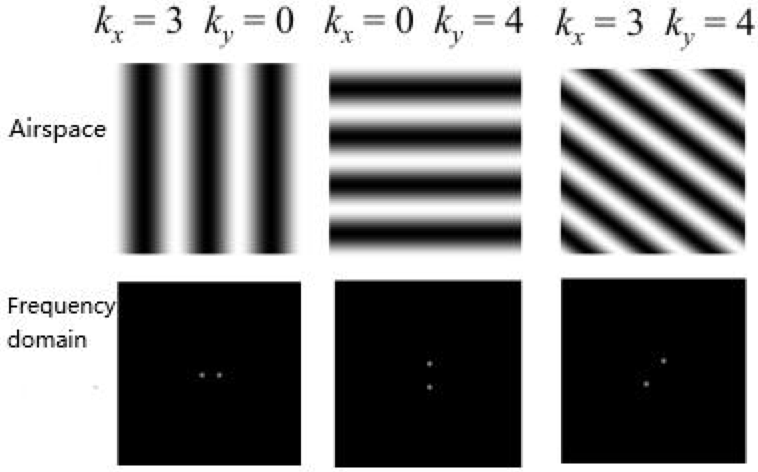

Fig. 1 Cosine fringe Structured light with different spatial frequencies

Cosine fringe Structured light provides a convenient means to obtain the Fourier coefficients of any frequency components of an image. Taking the four step phase shift as an example, the cosine fringe Structured light with spatial frequency kx=3 and ky=4 has four different initial phases, namely 0, π/2, π, and 3 π/2, as shown in the first line of Figure 2.

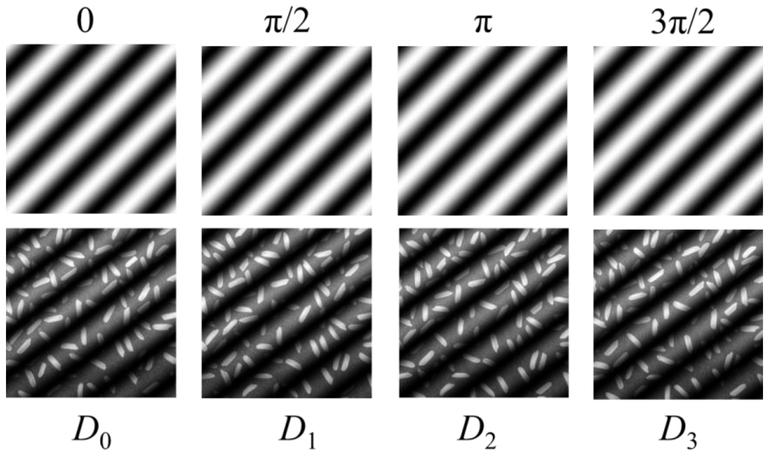

Fig. 2 Cosine fringe Structured light with different spatial frequencies

Taking Matlab's own example image "rice" as an example, shine these four kinds of Structured light on the original image, that is, dot multiply the two image matrices, and the result is shown in the second line of Figure 2. Sum all the element values of the matrix after point multiplication to obtain D0, D1, D2, and D3, respectively.

$$F\left(k_x, k_y\right) = \left(D_2 - D_0\right) + i\left(D_3 - D_1\right) \quad (1)\,(1)$$

According to the mechanism of single pixel imaging illuminated by Structured light, we can obtain the Fourier coefficients of the spectral components of the image frequency kx=3 and ky=4 by using formula (1). By changing the frequency of Structured light, we can traverse the Fourier coefficients of all frequency components to obtain the spectrum of the image. Take the picture "rice" as an example, use Structured light illumination to extract the Fourier coefficients of different frequency components of the image one by one, and finally obtain the image spectrum as shown in the middle sub image of Figure 3.

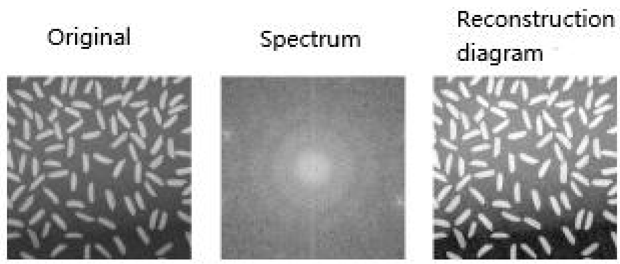

Figure 3 Original image, spectrum, and reconstructed image of "rice"

Based on the frequency spectrum of the image, using a two-dimensional inverse Fourier transform, we can recover the spatial image from the Fourier coefficients in the frequency domain, and the corresponding reconstructed image is also shown in Figure 3. As shown in the figure, the reconstructed image is very similar to the original image. After calculation, the structural similarity between the original image and the reconstructed image is 1.

3. The contribution of different spectral components to image information

Frequency domain image processing is the main method and means of image processing. After learning and mastering the spatial and frequency domains of images and their mutual transformations, using different spectral components to reconstruct images can achieve different processing effects. Taking the image "rice" as an example, if only 20% of the low-frequency components are retained in the frequency domain, the reconstructed image can also reproduce the original image well, as shown in the first line of Figure 4. In the reconstructed image with 20% low-frequency component recovery, the rice grains are clearly distinguishable, and the reconstructed image retains most of the information of the original image, with a structural similarity of about 0.81 between the two.

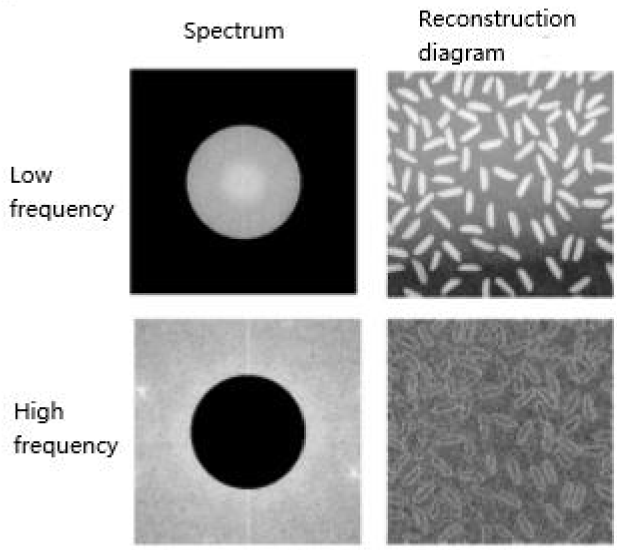

Figure 4 Reconstruction diagram using low-frequency and high-frequency components for recovery

If 80% of the high-frequency components are used to generate the reconstructed image, as shown in the second line of Figure 4. At this point, only some rapidly changing boundaries in the original image, such as the contours of rice grains, are retained in the reconstructed image. The low-frequency component reflects the main body of image information, while the high-frequency component reflects the details of image information. Combined with the main and secondary contradictions in materialistic Dialectic, a small number of low-frequency components occupy the main body of image information, which is the main contradiction, while a large number of high-frequency components carry less useful information, which is the secondary contradiction. It can be seen that in the process of image processing, focusing on handling the low-frequency components as the main contradiction can achieve satisfactory results.

4. Guide students to try and expand frequency domain image processing

Teaching fish is not as good as teaching fish. Based on mastering basic concepts and skills, students are required to expand and research the teaching content appropriately, which is beneficial for mobilizing learning enthusiasm and initiative.

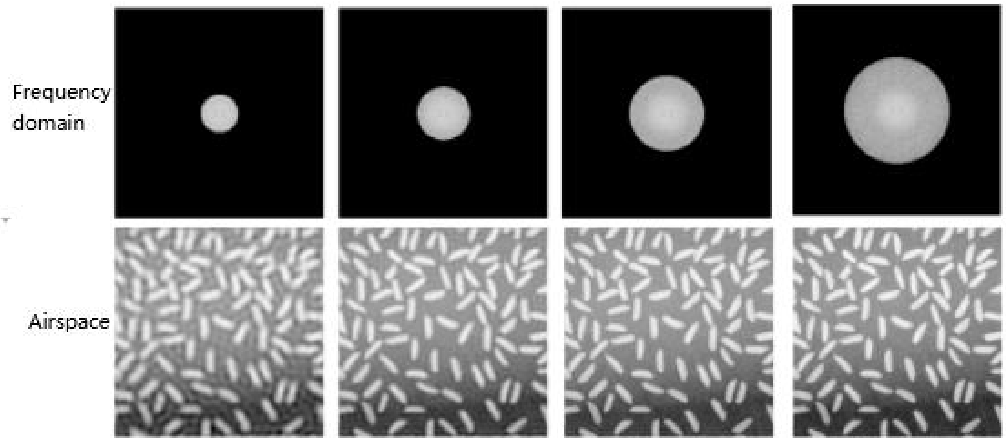

Figure 5 Reconstruction diagram under different sampling rates

For example, the low-frequency component contains the main body of image information, but the ratio of the low-frequency component to the entire spectral component can affect the quality of the restored image. Figure 5 shows the spectral distribution and corresponding reconstruction of "rice" under different sampling rates. It can be seen from Figure 5 that the more spectral components collected by Structured light lighting, the better the recovery quality of the reconstructed image. When the frequency domain retains too few spectral components, a large number of artifacts appear in the reconstructed image of "rice", the morphology of the rice grain tip cannot be recognized, and the information carried by the image is missing more. The structural similarity between the reconstructed image and the original image rapidly decreases with the proportion of low-frequency components retained.

Reasonable homework and scientific evaluation methods can help promote the absorption and internalization of knowledge. For image reconstruction, selecting different spectral parts and changing the processed image objects can also cause changes in the reconstructed image. These further exploration contents can be assigned to students as group research assignments based on their situation and submitted in the form of small papers. Teachers evaluate students' achievements from the perspectives of completed workload and innovation, and can use this assignment as an important part of the course process assessment.

5. Conclusion

Structured light illumination provides a powerful tool for extracting Fourier coefficients of different spectral components of an image. Using Structured light illumination to obtain image spectrum can make students understand the Unity of opposites between image spatial domain and frequency domain more vividly. Through the acquisition of image spectrum, image reconstruction, and the imparting of knowledge and skills on the role of different spectral components, it helps guide students to view images and the information carried behind them from the perspective of frequency domain, freely and flexibly switch between airspace and frequency domain, and possess corresponding professional skills and literacy.

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